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Experts reveal the big discoveries changing our world

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The new diet tailored to your DNA

The best solution to the plastic problem

Inside the next Mars rover mission

The first photo of a black hole

The digital silk road

Maths to combat terrorists

Prescription psychedelics

China transforms conservation

Drone traffic control takes off

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The year ahead...

It goes without saying that the planet's plastic problem, the changing climate and air pollution will keep scientists and editors busy next year. If you think about it that way, the New Year can seem a bit depressing. But 2019 could present some neat solutions to the messy problems of the 21st century.

For one, immunotherapy – using the body's own equipment to tackle illness – has the medical community fizzing with excitement. The hope is that doctors might soon have a single weapon they can hone to tackle the multitudes of cancers seen in their patients.

Neural networks – deep-learning algorithms that can crunch through oceans of data to spot patterns invisible to the human eye – provided no end of breakthroughs in 2018. These number-crunching machines embarrassed chess and Go champions, bettered doctors at patient diagnosis and learned to drive. But I think, next year, we might see how all the requests listened to by the likes of Siri and Alexa have taught their neural networks to speak like us.

On a more profound note, there have been some promising pilot studies this year investigating how deep-learning systems could help doctors diagnose early developmental delays in children with autism. This is such a hard thing to do: to spot whether a behaviour is harmless or the sign of something serious. If an algorithm could help doctors spot the signals earlier, it will be a massive boon to parents and their kids.

Finally, as a greedy person, I'm excited to see how food evolves next year. Personalised nutrition sounds boring, but I'm holding out for a microbiome text that'll tell me my gut bacteria are exceptionally good at dealing with bacon and eggs.

Daniel Bennett, Editor

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PROF TIM SPECTOR is professor of genetic epidemiology at King's College London and head of the British Gut Project.

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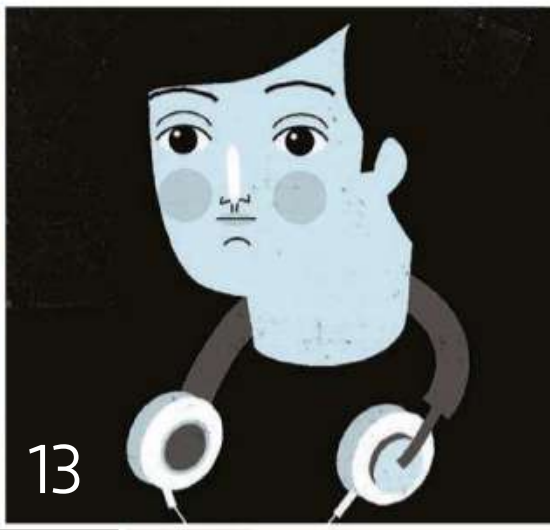
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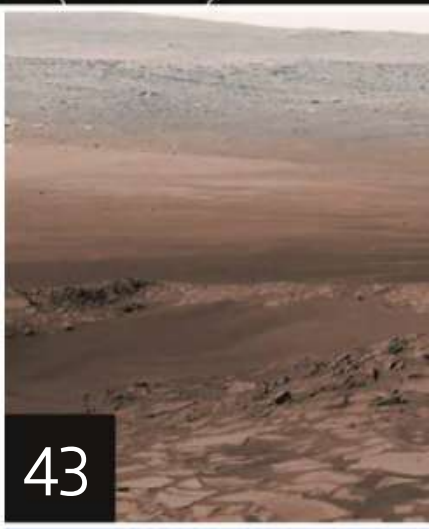
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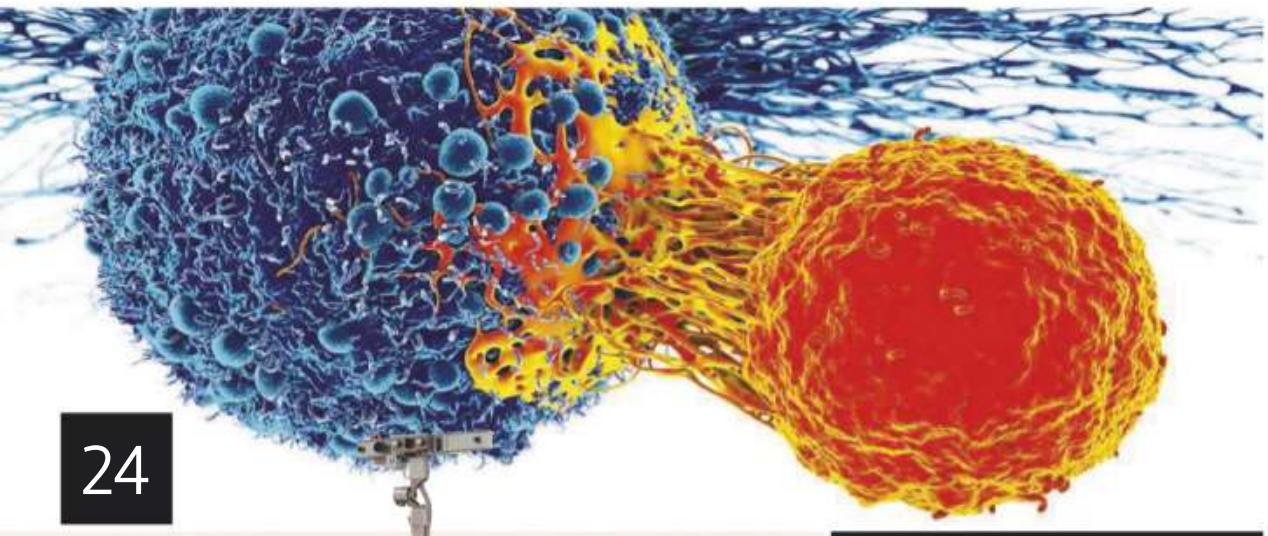

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From foes to friends: bacteria join the fight against cancer

Scientists have identified a bacterial strain that can be used against prostate cancer. This is a new example of how bacteria's anti-tumour properties can be enlisted in designing new cancer therapies.

In 10 seconds? Researchers studying prostate pain found a rare strain of bacteria that can make treating prostate cancer much more effective by enabling checkpoint inhibitor therapy.

Checkpoint what? Checkpoint inhibitor therapy. In some cancers, we can switch off the false signals that cancer cells send to stop the immune system from destroying them. This approach is called checkpoint inhibitor therapy, but it doesn't work in prostate cancer, as these tumours don't provoke an immune reaction.

So how can bacteria help with that? Researchers found a strain called CP1 that always migrates to the prostate, where it causes an inflammation – and triggers an immune response – making checkpoint inhibitor therapy possible. Scientists tested this on mice and found their prostate cancer survival rates doubled, due to immune cells being activated.

Wait, I thought some bacteria caused cancer? And so they do, but we've also known for a while that some of them can stunt and kill certain tumours. This is because they reduce the oxygen and nutrient supply that keeps those tumours alive.

If we knew this, why haven't we used them before? Two words: side effects. Most bacterial therapy uses live bacteria, which obviously can cause infections and toxicity. Also, more investigation is required into whether these bacteria can acquire antibiotic resistance, making those infections untreatable.

Is there a way out? Yes, our team has managed to inactivate a strain of bacteria, Clostridium sporogenes, with heat. Then we tested its anti-cancer powers against colorectal cancer cells grown in the lab, and in lab mice. We found that it stopped tumour growth in both cases and the formation of new tumours in the mice.

So, bacteria are now our friends in the fight against cancer? Some of them certainly are! Therapies using heat-inactivated bacteria and those based on strains that turn 'cold' cancers 'hot' open up the possibility to better treat a range of cancers.

Madhura Bhave is a PhD Student, at Nanyang Technological University, Singapore researching bacterial derivatives of *Clostridium sporogenes* for anti-cancer therapy.

Scan this QR code to discover all the research behind Madhura's 3-minute summary on Sparrho

Background photograph by @rawpixel

"The ceaseless revolution in our understanding of human evolution shows no signs of slowing down. In 2019, expect more revelations – new characters, more sex and exciting drama in the epic story of us."

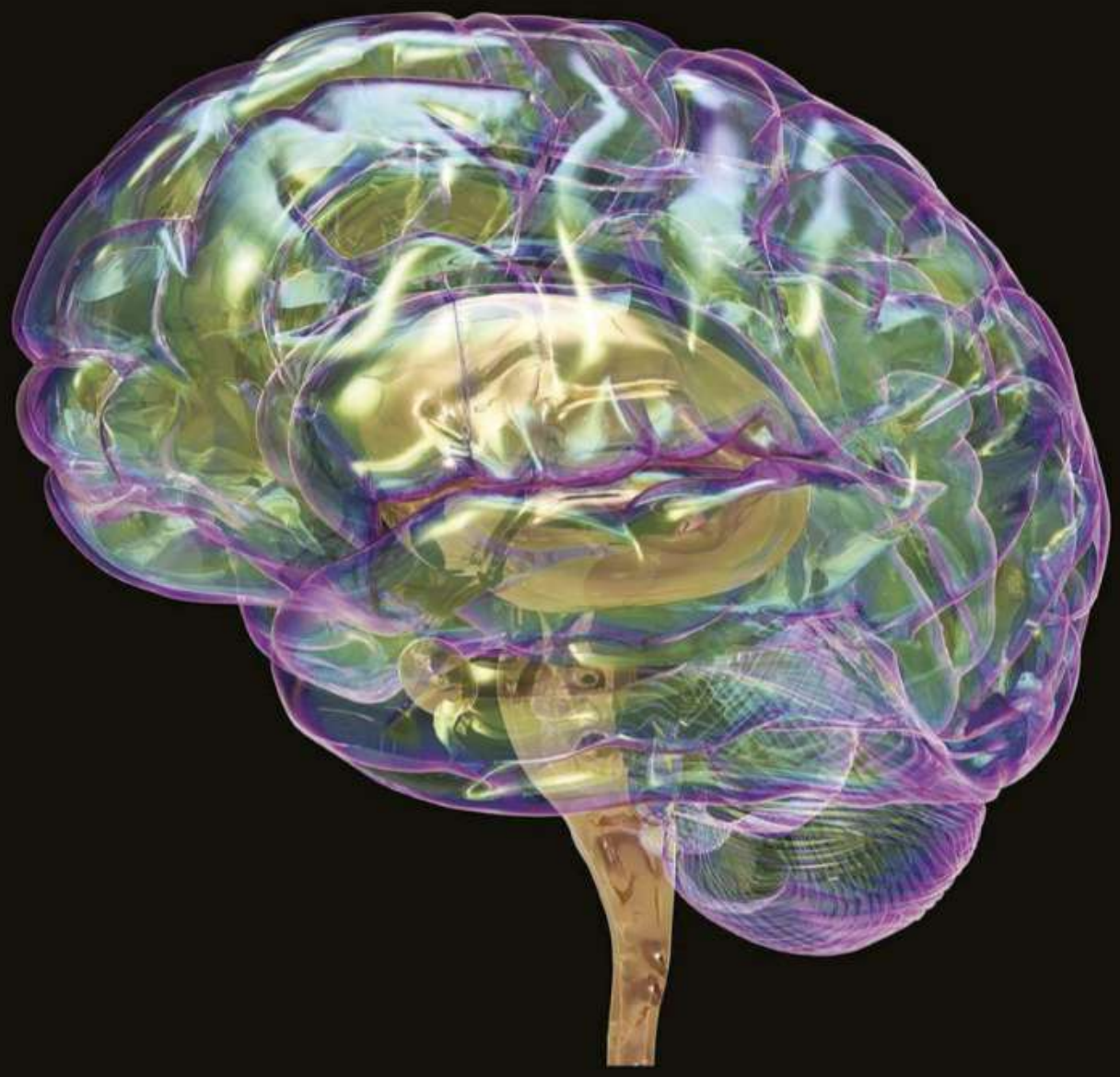
DR ADAM RUTHERFORD
author and broadcaster, presenting BBC Radio 4's Inside Science

"The new Fast Mimicking Diet (FMD) is currently being tested in a number of medical centres around the world, with results expected in 2019."

DR MICHAEL MOSLEY
author and broadcaster, presenting the BBC series Trust Me, I'm a Doctor

"Huge advances are being made in ancient DNA, uncovering how our ancestors migrated and bred with other human species. I expect 2019 will see history rewritten before our eyes."

ANGELA SAINI
author of Inferior



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HEALTH
IN 2019

YOUR PERFECT PLATE

Next year's on-trend diet will be food tailored to your genome

WORDS: **HAYLEY BENNETT**

We're always being told what to eat to lose weight, prevent cancer or sleep more soundly. But what if pumpkin seeds and papaya just aren't doing it for you? Not everybody's body works the same and the one-size-fits-all dietary recommendations dished up by the media and public health campaigns are starting to look outdated. Instead, some nutrition experts suggest we need to tailor our diets to our DNA. The future of food, they suggest, is in 'personalised nutrition'.

We've known for a long time that everyone processes food slightly differently, but this knowledge is now being supplemented by information about our genes, shedding new light on individual food issues and preferences.

Many of us, for example, struggle to deal with dairy. "Some people have the ability to metabolise lactose – the primary sugar found in dairy – whereas others do not," explains University of Toronto nutrigenomics expert Ahmed El-Shomey. "Those with an impaired ability end up fermenting it in their colon and that results in diarrhoea, bloating and gas." Why can't everyone digest lactose though? Individual genomic data gives us a better insight: those who can't have a variation in a gene called LCT.

Similar can be said for caffeine. Because of a variation in the CYP1A2 gene, some people can drink four cups of coffee a day with no ill effects while others start to increase their

GETTY X2

Individual genomic data tells us people who can't digest lactose have a variation in the LCT gene

risk of heart disease and diabetes at just two.

On top of your genes, the particular mix of bacteria in your gut can affect your dietary responses. In 2017, Israeli researchers showed that people's gut microbiomes determined what happened to their blood sugar levels after eating bread. Using only data about a person's gut bacteria, they were able to predict accurately whether that person's blood sugar would see a greater spike after eating sourdough bread or ordinary white bread.

So does this mean that, very soon, anyone watching what they eat will need a genome sequence and a microbiome profile just to decide what to make for dinner? Not necessarily. We can tell a lot about the way our metabolism works from carrying out straightforward tests – like the blood sugar test – after eating certain foods. These other tests have the advantage of showing us how our body actually reacts, not just how we think it should react based on our genes. This is important because our response to food is a result of the combination of our DNA and our lifestyle. However, as El-Shomey points out, a genetic test is actually pretty simple these days, compared to, say, a lactose intolerance test, and more useful for long-term planning. "It's probably the most reliable type of test that can indicate a person's lifetime metabolic differences," he says.

It might sound like a futuristic way to make a meal plan, but the future is already here. In 2011, El-Shomey founded the personalised nutrition company Nutrigenomix, which now provides saliva test kits and genotyping services to 8,000 clinics in 40 countries. In the next few years, we'll likely see more companies offering these kinds of services and a continuing explosion in nutrigenomics research.

One exciting area of current research focuses on the 'fat mass and obesity-associated' or FTO gene, which plays a role in governing metabolic rate and energy regulation. Back in 2007, a UK-wide study linked the FTO gene to differences in people's risk of developing diabetes and more recently it's been shown that it influences how people respond to weight-loss surgery. Now, we're discovering that variations in the FTO gene also determine whether a person is likely to lose weight on a high-protein diet.

If you think all this tailored nutritional advice sounds like it could cause a headache at the family dinner table, consider what you're already doing to make your meal your own, says El-Shomey – adding salt after serving up, skipping dessert or taking another helping of veggies. "Families have been personalising each person's meal for a very long time," he says. So maybe personalised nutrition is just the next logical step.

TAKE A TEST

Today, there are already plenty of companies offering personalised nutrition services and anyone can pay to have their DNA analysed. All you have to do is send a saliva sample off to a lab, where scientists test it for a range of genetic variations that are important in metabolism. The results tell you whether you are any more at risk of certain diseases than the general population and what this means for how you manage your diet. Nutrigenomix sends out reports to its clients, giving them a detailed breakdown of what their genes say about how their body processes proteins, fats, vitamins and key molecules like caffeine and gluten. Alongside the results, the report provides insights such as "you have a high preference for sugar" and recommendations like "consume 20-30 per cent energy from fat". Crucially, it's up to the client to do the rest.

SHOULD WE ALL GO VEGAN IN 2019?

Widespread dietary changes are needed if we're to combat the range of health problems associated with obesity and the environmental damage caused by industrial scale farming. Switching to a vegetarian or vegan diet is a potential solution, but selling the idea to the meat-eaters around the world is a tricky proposition. But scientists are coming up with ways to widen the menu WORDS: **JOSH GABBATISS**

Algae

Seaweed grows quickly and is a core part of Japanese diets. As it can be grown at sea, it would solve the issue of dwindling land for crops. There are thousands of varieties that could be farmed and eaten.

Wheat gluten

Also known as wheat-meat, seitan or mock duck, wheat gluten is made from the 'glue' of wheat. As well as having a higher protein content than more well-known meat substitutes such as tofu, its chewy consistency also gives it a meaty texture. It's thought to have been first produced by Buddhist monks who adhere to strict vegetarian diets, and it's particularly popular in Asian cuisine. Although wheat gluten tastes bland on its own, it's good at absorbing flavours.

Artificial meat

Back in 2013, the world watched as food critics tucked into the first ever lab-grown burger. The small pink patty, prised out of a petri dish and fried in front of the media, was proof that it was possible to grow safe and edible meat without slaughtering a single animal. There was just one problem: the patty had taken two years and over $300,000 (£231,000) to produce. Fast forward a few years and costs have plummeted. One company who makes artificial meat – Memphis Meats – says it costs $2,400 to produce, due to the pricey medium needed to culture cells. But the company aims to reduce that cost to under $5. The key is scaling up the technology to the level of an industrial food process. Polls suggest there's a willingness to give this modern meat a go. A survey by *The Guardian* found that 68 per cent of people wanted to try cultured meat. But whether people reach for cultured burgers at the supermarket is a different matter entirely.

Synthetic milk

Perfect Day is one of the companies developing cow-free milk. Milk-producing genes are inserted into yeast, which are then bred to produce milk proteins. The company, based in Cork, has raised €20.9m to get its milk to market.

BBC TWO

Trust Me, I'm a Doctor discusses veganism
bbc.in/2oFMoNg

Fungi

No, not mushrooms – mycoprotein. You'll probably recognise the brand Quorn, named after a Leicestershire village. Quorn is made by growing the filamentous fungus (mould) *Fusarium venenatum* in fermentation tanks. The mycoprotein used to be marketed as 'mushroom protein' until manufacturers were told to stop by the Advertising Standards Agency. It's now described as a "member of the fungi family". Earlier this year, a report claimed Quorn worldwide sales increased by 16 per cent last year (and 25 per cent in the US) and is set to become a billion-dollar business in the future.

GETTY X6, MEMPHIS MEATS

COULD GOING VEGAN SAVE THE PLANET?

According to figures from the Consultative Group on International Agricultural Research one-third of our greenhouse gas emissions come from agriculture. But that's just one factor. Our food system is also the leading cause of deforestation, land use change and biodiversity loss in the world. Then there's overfishing, pollution, groundwater depletion, excessive fertiliser use and pesticides to contend with as well. So what can be done?

A paper published in 2016 in *Proceedings Of The National Academy Of Sciences* concluded that a mass switch to vegetarianism would bring down food-related greenhouse gas emissions by a whopping 63 per cent. Even just sticking to global health guidelines regarding meat consumption would be enough to reduce emissions by 29 per cent.

Going vegan, however, seems to have the edge in the planet-saving stakes. Many of the issues that arise from farming livestock for meat – methane emissions from animal digestion, pollution from farms, energy-intensive feeds – also apply to the dairy and egg industries. If widespread veganism was adopted, that 63 per cent reduction in emissions shoots up to 70 per cent.

Despite this, it's thought only 2 per cent of the UK population is vegetarian, and less than 1 per cent is vegan. But maybe cutting out animal products isn't necessarily the way to go.

Some research has suggested that at least some degree of carnivory could be beneficial. A recent analysis of 10 diets, each with a different ratio of meat and animal products, saw veganism relegated to fifth place when it came to maximising sustainable land use, below different degrees of vegetarianism and omnivory.

Relatively simple changes can make a difference, but when considering the scale of our food system's impact on the planet, something bigger might be necessary. Industrial agriculture has been our go-to system for decades, but the overuse of chemical pesticides and fertilisers is resulting in degraded ecosystems that are not sustainable.

A solution could be agroecology, a fancy term for restoring biodiversity and ecosystem functions in order to ensure productivity. These principles are already being put into action. As it stands, rice accounts for up to a third of our annual water use, but a low-water agroecological method known as System of Rice Intensification (SRI) is increasingly being used to produce rice yields up to 50 per cent larger. Water is only applied to the rice when needed, compost is used instead of chemical fertilisers and farmers weed by hand instead of using herbicides. Using this method, Sumant Kumar, a farmer from the Indian state of Tamil Nadu, has smashed the previous annual rice-growing record by an astonishing three tonnes.

A truly environmentally friendly diet relies on major systemic changes, but individual diets also need to change. The variety of data on offer can give the impression of flip-flopping within the scientific community, but it's more indicative of the sheer complexity of the subject – not to mention the competing interests of stakeholders in the food industry.

TALKING POINT

TIM SPECTOR

The professor of genetic epidemiology at King's College London, and head of the British Gut Project, explains why the microbes in your belly are is so important

WORDS: **AMY FLEMING**

I can tell more about someone's health by getting a detailed screen of their microbes than by screening their genes. We're 99.7 per cent genetically similar, whereas we only share about 20 or 30 per cent of our microbes. Yet microbiome knowledge is 10 years behind human genetic research.

If you're on cancer chemotherapy, and you have the right type of microbes, you'll be three times as likely to survive. So everybody going onto chemotherapy should be getting their microbiome tested. Indeed, it's looking like microbes do work for a wide variety of conditions. If you've got a child with diarrhoea, giving them probiotics will significantly speed up recovery time. And people with diabetes, rheumatoid arthritis, food allergies, IBS, colitis and high blood pressure tend to lack these beneficial microbes that are protective in other people. Being constipated, having a limited diet, feeling bloated; on average, if you're overweight, unwell and have lots of allergies, you're going to have poor gut health.

Find foods that support your glucose levels, then you're more likely to lose weight long term. If I eat pasta or rice, I don't get a spike, whereas other people might have the opposite. It's the microbes determining that. We're all unique.

I could test your gut microbes and say whether you should be a rice or a potato person. As more people use web-based microbiome testing, it's going to go down to £50. If the NHS did it, the price would be below £20 – the same as a blood test and more useful.

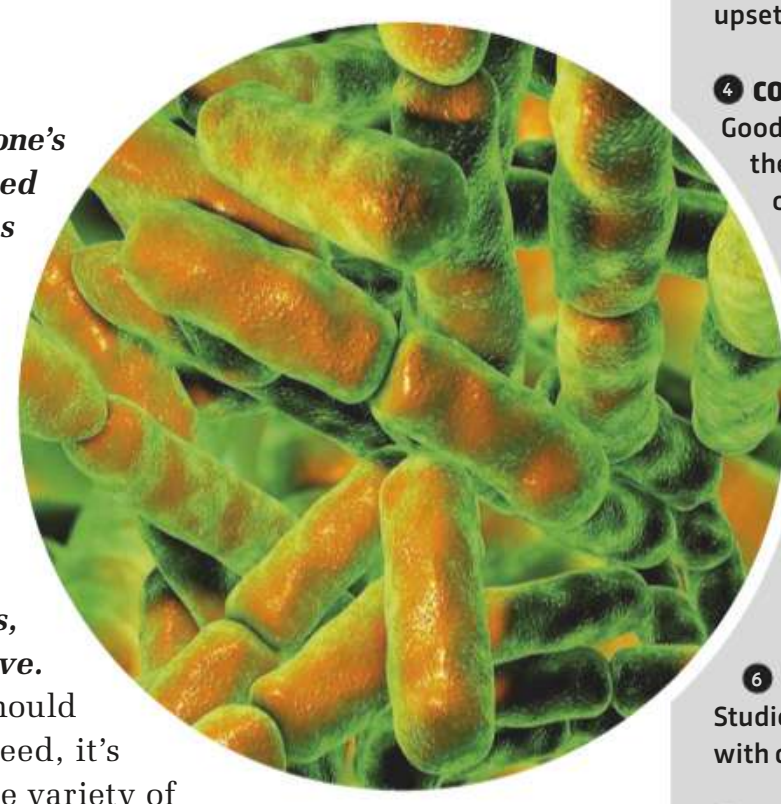


Illustration of Bifidobacterium in the human intestine

MICROBE BOOSTERS

1 UP YOUR FIBRE INTAKE
Aim for more than 40g per day, which is about double the current averages. Fibre intake has been shown to reduce heart disease and some cancers, as well as reduce weight gain.

2 EAT A VARIETY OF FRUIT & VEG
Each fruit and veg support different microbial species. Pick high-fibre veg, such as artichokes, leeks, onions and garlic, which all contain high levels of inulin (a prebiotic fibre). Lettuce has little fibre or nutrient value.

3 AVOID ARTIFICIAL SWEETENERS
Aspartame, sucralose and saccharine disrupt the metabolism of microbes and reduce gut diversity – in animal studies this has led to obesity and diabetes. Ditch the processed foods too, as these also upset microbe metabolism.

4 CONSUME FERMENTED FOODS
Good choices are unsweetened yoghurt; the sour milk drink kefir; raw milk cheeses; sauerkraut; the Korean dish kimchi; and soybean-based products such as soy sauce.

5 GO WILD
People living in rural areas have better microbes than city-dwellers. Gardening and other outdoor activities are good for your microbiome. Excessive washing and use of antibacterial sprays may not be.

6 STROKE ANIMALS
Studies have shown that people living with dogs have more microbial diversity.

7 STEER CLEAR OF ANTIBIOTICS
Antibiotics destroy good and bad microbes, and it can take weeks to recover, so don't take them unless you need them. Their use is also associated with obesity and allergies in animals. Even paracetamol and antacids can interfere with microbes.

8 AVOID SUPPLEMENTS
Only a tiny proportion of supplements have been shown to be beneficial. Instead, focus on eating a diverse range of real food to get all your nutrients.

9 CONSUME ANTIOXIDANTS
Polyphenols in nuts, seeds and tea are antioxidants that act as fuel for microbes.

ALAMY, GETTY

ALL ALONE

The government is trying to tackle the rise in the number of lonely people, while scientists are investigating how to stop loneliness making us ill

WORDS: **MOYA SARNER**

Society is becoming ever more divided. But if there is one thing that's bringing everyone together, it's loneliness. One recent study found that nine million adults in the UK suffer from chronic loneliness: if they all moved to one city, it would be bigger than London.

This isn't just sad, it's dangerous. Research shows that experiencing chronic loneliness is as bad for our health as smoking 15 cigarettes a day and worse than obesity. It's associated with an increased risk of coronary heart disease and stroke, and increases our likelihood of early mortality by 26 per cent. But how can an emotional experience be so bad for our physical health?

RE-WIRING THE BRAIN

Prof Steve Cole, a medicine and genomics researcher at the University of California, Los Angeles, says part of the answer may lie in the impact loneliness has on our immune system. His research shows that the cells in the immune systems of chronically lonely people change: instead of being primed to fight viruses, the cells prepare to fight bacterial infection – the kind that follows a wound or injury. This is usually a temporary state associated with the fight-or-flight response, but lonely people get stuck in it. Long term, this leads to higher levels of inflammation, which contributes to cancer, heart attacks, Alzheimer's and depression.

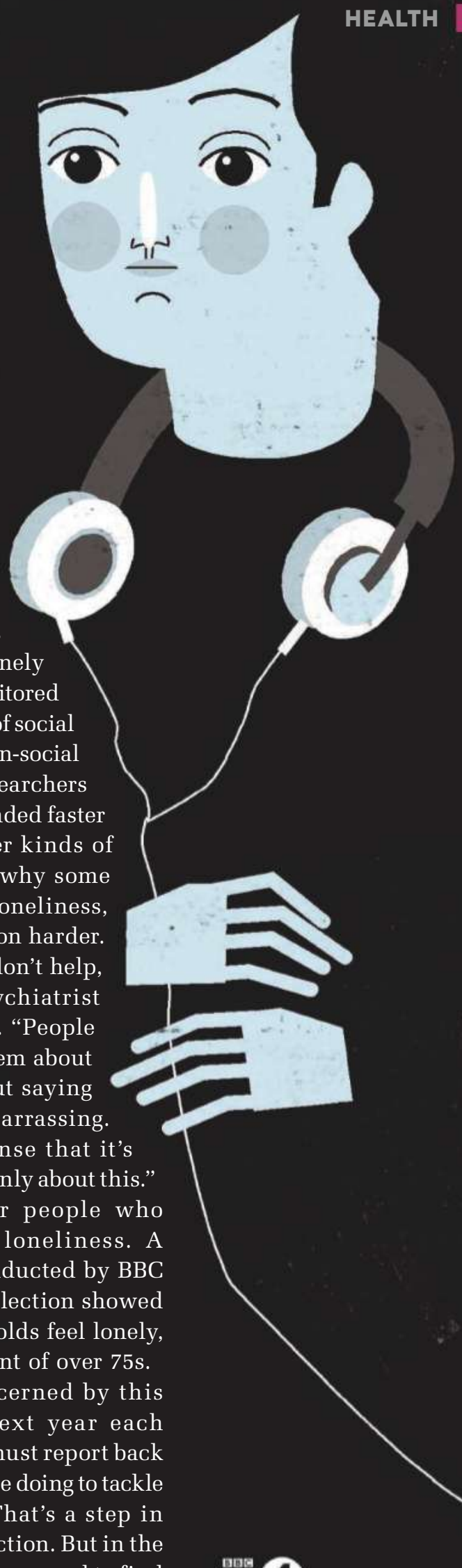
When these inflammatory signals reach the brain, they change how it functions, making us more defensive and prickly, and more lonely as a result. Scientists have seen this in brain scans: in one study, lonely people's brain activity was monitored while they were shown images of social threats, such as bullying, and non-social threats, such as sharks. The researchers found that lonely people responded faster to social threats than to other kinds of dangers. This might explain why some of us become entrenched in loneliness, as it can make social interaction harder.

Our attitudes to loneliness don't help, says Dr Farhana Mann, a psychiatrist at University College London. "People will go to their GP and tell them about whatever lesion they have, but saying they're lonely is just too embarrassing. We need to give people a sense that it's absolutely legitimate to talk openly about this."

Surprisingly, it's younger people who seem to suffer more from loneliness. A recent nationwide survey conducted by BBC Radio 4 and the Wellcome Collection showed that 40 per cent of 16-24 year olds feel lonely, compared with only 27 per cent of over 75s.

40 per cent of 16-24 year olds feel lonely, yet only 27 per cent of over 75s

The government is so concerned by this that from next year each department must report back on what they're doing to tackle loneliness. That's a step in the right direction. But in the years to come we need to find ways to help lonely people that work across the full spectrum of their experiences of the condition.



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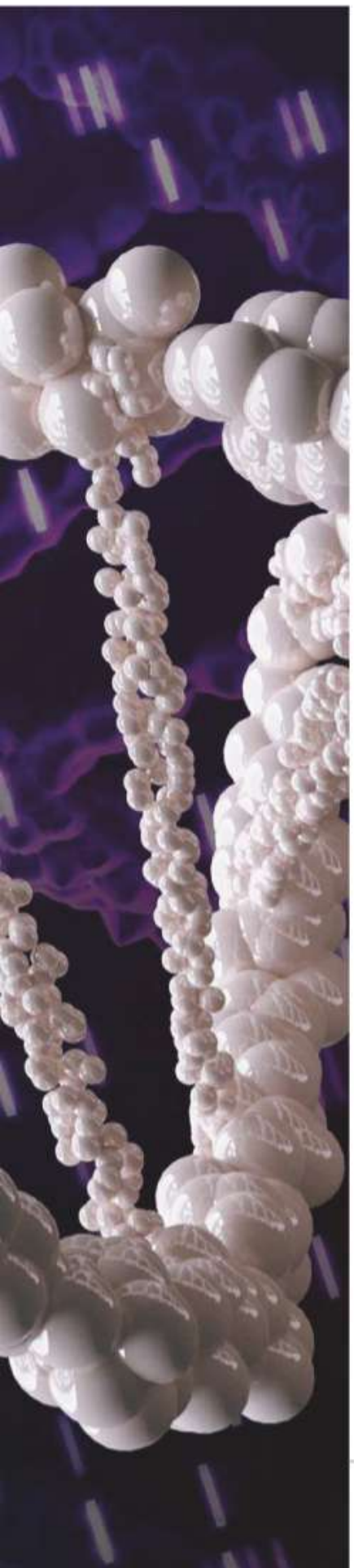
BBC RADIO 4

Listen to a series of *All in the Mind* on loneliness **bbc.in/2Sb2uMn**

THE GENETIC **REVOLUTION**

CRISPR looks set to be the future of gene editing. But experts are cautioning that this revolutionary technique needs to be developed carefully. So what do the next few years hold?

WORDS: **KAT ARNEY**



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It's impossible to miss the hype around CRISPR – a new form of genetic modification that promises to revolutionise the field of gene therapy. Unlike older forms of genetic manipulation which are based on adding or swapping whole sections of DNA, CRISPR is a technique known as gene editing, allowing scientists to make precise changes in the genome down to the level of a single DNA 'letter' (see 'How CRISPR works' on page 16).

In recent years we've seen academic and commercial researchers racing to get gene editing working in everything from tiny nematode worms and lab-grown cells to plants, animals and even humans. So how can we expect to see this powerful technology being used in the not-too-distant future?

Most of the excitement around CRISPR centres on its potential for treating human diseases, especially life-threating disorders caused by a fault in a single gene. In 2016, researchers at the Salk Institute in California used CRISPR to modify cells in the eyes of rats with a genetic form of blindness, partially restoring their sight – the first time the technique had been shown to work in adult mammals. Since then there has been promising progress towards gene editing therapies for a huge range of illnesses, from inherited metabolic problems and hereditary heart failure to cystic fibrosis and conditions affecting the brain, such as Huntington's disease or even (more controversially) autism.

Because it's tricky to deliver CRISPR into cells throughout the body, researchers have their sights set on relatively easy-to-access tissues such as the blood, skin, muscle and liver – for example, using CRISPR to convert liver cells into miniature 'protein factories', pumping missing molecules back out into the body. Another intriguing idea on the horizon involves using CRISPR to edit a sample of skin cells in the lab, growing them into a personalised skin patch for delivering hormones or other biological molecules.

Muscle-wasting disorders are also a target. Although the faulty gene responsible for Duchenne muscular dystrophy is very large, making it tricky to repair with CRISPR, scientists in Texas announced in August that they had managed to edit a 'hotspot' within the gene in beagle puppies with the disease – a fix that could work for up to 15 per cent of patients if the results translate into human trials.

Infectious diseases are another development on the horizon. In May, Japanese researchers used CRISPR to cut hidden HIV viruses out of the genomes of infected human immune cells growing in the lab. Unlike conventional anti-viral drugs, which control the virus but don't get rid of it entirely, the development of a CRISPR-based therapy paves the way for the complete eradication of the disease from infected carriers.

GENE EDITING ON TRIAL

Despite these exciting ideas, recent snags suggest that getting gene editing into the medical mainstream isn't going to be easy. This year saw the launch of the first clinical trials of CRISPR-based gene therapy in the US and Europe, using the technique to repair the faulty genes in blood stem cells that are responsible for causing sickle cell anaemia and beta-thalassaemia. Meanwhile, doctors in China are already recruiting patients into clinical trials testing CRISPR-modified immune cells that have been programmed to attack different types of cancer.

However, researchers at the Karolinska Institute in Sweden sounded a note of caution

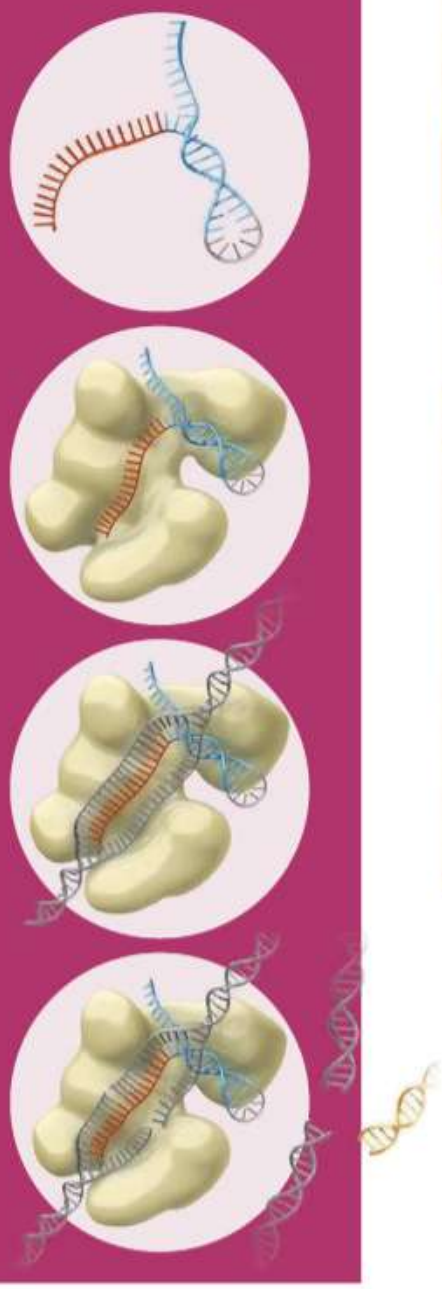
HOW CRISPR WORKS

1 Scientists design a 'CRISPR' made from RNA. It includes a series of letters that matches a unique DNA sequence within an organism's genome.

2 The CRISPR molecule is attached to 'Cas9' (shown here in beige). This is an enzyme that uses its RNA 'guide' to recognise the target DNA sequence.

3 The CRISPR-Cas9 tool cuts the strands of the target DNA's double helix, then the cell's repair machinery will fix the damage – minus the old DNA sequence.

4 The CRISPR technique can be used to delete unwanted DNA, or to find and replace a sequence by adding genetic material – such as a new gene.



SPARE PARTS

Stem cell technology has advanced to a point where scientists can grow replacement tissues or even whole organs in the lab. It's also now possible to reprogramme cells from a small skin sample back into stem cells, then convert them into neurons, muscle, liver and more. Adding in gene editing makes for a powerful combination, fixing faulty genes in a patient's own cells to make personalised 'spare parts'. One idea coming down the pipeline includes using CRISPR to create 'universal donor' blood cells, which could be grown at industrial scale and given to patients needing blood transfusions or stem cell transplants. Scientists are also using gene editing to slice harmful viruses and incompatible genes out of pigs to make their organs suitable for human transplantation.

ABOVE: Microbiologists are researching the role of RNA and proteins that control cellular processes

BELOW: Scientists reconstructed urethras using the patients' own cells

in June when they announced that CRISPR might increase the risk of cancer by activating an 'immortalising' response in cells. Other groups have raised fears of 'off target' effects – unintended accidental alterations in critical genes or control switches.

As a result, the FDA has put the current US CRISPR trial on hold, asking for more safety information. Ambiguous results from another gene editing study – this time using a related technique known as 'zinc fingers' to target a gene involved in a disease called Hunter syndrome – have also cast doubt on the effectiveness of the approach.

Patients and the public should therefore be cautious not to believe too much hype about gene editing over the coming years, warns Jackie Leach Scully, Professor of Social Ethics and Bioethics at Newcastle University. These treatments are only just entering clinical trials, and there's a lot we still don't know about their safety and effectiveness.

"I think we're more sophisticated nowadays, more savvy and alert to the idea that these technologies get hyped up, but when you're dealing with human disease

ALAMY, WAKE FOREST UNIVERSITY SCHOOL OF MEDICINE

and disability, there's a great yearning among patients and families for something that works," she says. "There's a lot of hope around some of these technologies, but they could take decades to get here and may not be quite as good as we believed at the outset."

DESIGNING BABIES

The current CRISPR talk is mainly focused on editing cells in the body, known as somatic cells, creating changes that can't be passed to future generations. However, Chinese scientists were the first in the world to announce that they had successfully managed to use gene editing to modify an early-stage human embryo back in 2015.

Since then, researchers in China, South Korea, the US and the UK have carried out similar experiments to fix various genetic disorders, although none of the modified embryos have ever been allowed to develop beyond a few days or implanted into a woman's womb. Many researchers in the field are now arguing that it's time to think seriously about how to move forward in this area, particularly for incurable, life-threatening conditions caused by single gene faults.

China's fast-paced research makes it likely the first germline edited baby will be born there, maybe even in the next decade

"I would say that in cases where there really is no alternative treatment, or preventative genetic screening, for a life-threatening condition then germline gene editing should be considered," says Yalda Jamshidi, a genetics specialist at St George's, University of London. "But this should only be done once the public and scientific and legislative communities have reached consensus about how we are going to use these techniques, how safe we need them to be, and whether we really are OK with it happening."

Although there is currently a ban on germline modification in most countries – altering genes in an embryo, eggs or sperm in such a way that could be passed on to future generations – it may only be a matter of time before this barrier is broken. Given China's fast-paced research in this area, combined with the country's willingness to reject international norms and dubious human rights record, it's highly likely that the first germline edited baby will be born there, maybe even within the next decade.

So, there are a number of technical advances in gene editing that we can expect to happen over the coming few years: improving accuracy and reducing off-target edits; increasing the number of changes per genome; finding more efficient ways to deliver CRISPR into cells; and the adoption of new techniques such as precision base editing, which rearranges the atoms in individual 'letters' of DNA and RNA rather than cutting and pasting in new sequences.

While all these developments paint an exciting picture of the future, Leach Scully says that we need to think carefully about where else gene editing could lead us. "Most people talk about the use of gene editing to eradicate or at least reduce the impact of diseases and disabilities, but there is also the potential to augment or enhance current human capabilities through these technologies," she says. "One is about making people better, the other is about making better people."

Although most gene editing research is focused on healing the sick, there will be people out there working on ways to give healthy people an advantage, such as building bigger muscles, boosting brain power, improving sporting ability, or even creating a genetically 'perfect' human. The emergence of cheap and cheerful (or quick and dirty) ways of editing DNA to order has attracted the attention of groups that are keen to disrupt the established order of biotechnology research, from scrappy startups designing new organisms that produce useful drugs or break down toxic waste to infamous mavericks like ex-NASA scientist Josiah Zayner, who injected himself with muscle-enhancing CRISPR components during a live-streamed talk.

It may be a long way off, but having access to tools that can fundamentally alter our genomes raises big questions about what it means to be human and what we value in society.

BBC RADIO 4

Listen to the programme *Editing Life* bbc.in/2F3CnEL

THE LAB BUILDING NEANDERTHAL BRAINS

It's not exactly resurrecting our extinct cousins but by growing Neanderthal mini-brains in labs, scientists are discovering more about our neurological differences and similarities, which might provide clues for treating autism, schizophrenia and more

WORDS: **JV CHAMARY**

Dr Alysson Muotri of the University of California, San Diego School of Medicine is trying to gain a deeper understanding of the brains of modern humans by growing Neanderthal 'mini-brains'. Otherwise known as organoids, these mini-brains are made with cells from the frontal cortex and could help explain humans' evolutionary success.

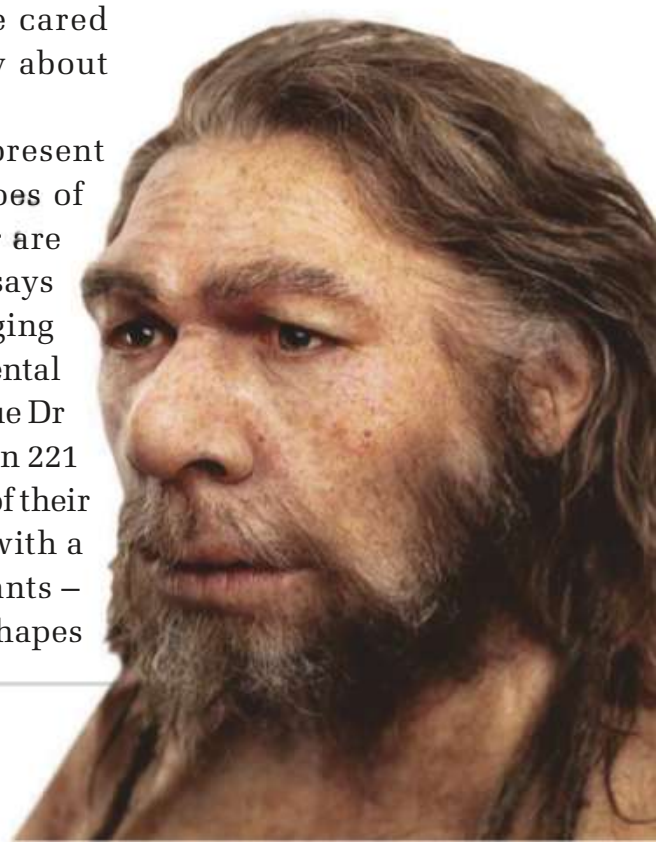
Growing organoids based on an extinct species is possible due to breakthroughs in several techniques: generating stem cells, extracting DNA from fossilised bones and gene editing. Muotri is making organoids through a process that he calls 'Neanderthalisation'. He edits genes in human cells, replacing one letter of DNA with the genetic variant carried by Neanderthals, then prompts those cells to develop into pea-sized balls of cortex tissue. The Neanderthal variant is identified by comparing human DNA to the Neanderthal genome, which was first sequenced in 2010 by a team led by Prof Svante Pääbo of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany.

One of the first human genes Muotri edited was NOVA1, which encodes a protein that controls when other genes are switched on or off. NOVA1 is known to be involved in early brain development because its mutations are linked to autism and schizophrenia. As organoids with the Neanderthal variant of NOVA1 mature, they develop defects in the synaptic connections between cells, scrambling their neural networks. Neanderthalised cells within the organoids also migrate in a manner that produces unexpected extra folding, says Muotri. "They look like popcorn."

SEEN IN A NEW LIGHT

We've begun viewing our extinct relatives in a new light lately. While this shift can be explained by archaeological finds that show a more sophisticated Neanderthal culture than was once assumed, the cynical explanation is that the shift has only happened since present-day Europeans discovered that interbreeding occurred between the two species. We've been forced to accept that we're more alike than we might previously have cared to admit – today, non-Africans carry about 2 per cent Neanderthal DNA.

The legacy of that mating is still present in our anatomy. "Even the small echoes of Neanderthal DNA that we all harbour are very much active in modern humans," says Dr Karen Berman, chief of the neuroimaging section at the US National Institute of Mental Health. In 2017, Berman and her colleague Dr Michael Gregory performed MRI scans on 221 healthy humans to construct 3D models of their heads. The work revealed that people with a greater number of ancient genetic variants – a higher 'NeanderScore' – have skull shapes



RIGHT: DNA can persist inside bones for thousands of years. By drilling into the bone, scientists can extract the DNA. This is how Neanderthal DNA was first obtained

BELOW: The Neanderthal brain was actually 10 per cent larger than a human brain

FRANK VINK, SCIENCE PHOTO LIBRARY

that more closely match those of our extinct cousins, which were elongated at the back. (We associate size with intellect, but the Neanderthal brain was 10 per cent larger.)

After sequencing DNA from the participants' blood samples, Berman and Gregory found that a higher NeanderScore also meant the cortex had more grey matter (brain cells) and white matter (mostly branching fibres from cells). Folding of the cortex was greater too, mirroring Muotri's popcorn-like organoids. The most affected areas were beneath the back of the skull: the occipital and parietal lobes of the cortex – regions that are involved in processing visual and spatial information.

The brain has limited resources, so allocating more to visual and spatial processing comes at the expense of other abilities. Those genetic variants that influence how a brain's resources are allocated seem to have given Neanderthals superior visual and spatial skills, probably for hunting. With modern humans, on the other hand, the trade-off meant that we had more processing power for social skills, contributing to our evolutionary success.

We're more like Neanderthals than we'd like to admit. Non-Africans carry about 2 per cent Neanderthal DNA

LESSONS FROM THE PAST

Ancient variants continue to affect humans today, as revealed by certain mental illnesses and neurological disorders. For example, 'neurotypical' people have one copy of a set of 25 genes located on chromosome 7, whereas a person with the condition 'Dup 7' has a duplication that creates two copies of each gene. This provides better visual and spatial skills but makes them less sociable – as in autism. At the other end of the spectrum, 'Williams syndrome' results from a deletion of those same 25 genes, leading to poor visual and spatial skills but hypersociability, which produces someone with a 'gregarious brain' who has a compulsion to strike up conversations with strangers.

So studying the impact of genetic mutations by comparing mini-brains, including those with ancient variants found in Neanderthals, can provide insights into conditions that affect humans today. "This could provide information not only about what makes us who and what we are, but also possibly pave the way for treatment and diagnostic approaches," explains Berman.

That's the main reason why Muotri is growing mini-brains. His lab contains thousands of mutant mini-brains for various diseases. He's already found that, like Neanderthalised structures, 'autistic' mini-brains have defects in their neural networks.

As Muotri says: "By understanding how the social brain evolved, we might be able to create better therapeutics."

LEGALISING HIGHS

Could a psychedelic trip soon be available on prescription?

WORDS: **TOM IRELAND**

Following campaigns by parents of children with severe epilepsy, doctors can now prescribe medical cannabis. For years the study and prescribing of cannabis-derived medicines have been restricted by UK drug laws, despite compounds in cannabis showing promise for a range of conditions, from epilepsy to anxiety to pain relief. But this could be just the start of sweeping changes to the way other illicit drugs are classified, too.

A growing body of research has shown that several other Schedule 1 drugs – including MDMA (ecstasy) and psilocybin (magic mushrooms) – can have a positive effect when combined with psychiatric therapy, helping patients overcome disorders such as depression, anxiety and post-traumatic stress disorder.

Experts believe that trials of these powerful hallucinogens will expand in 2019 and beyond, with the first treatments approved for use in perhaps five to 10 years.

"We're seeing a shift in how these drugs are perceived by the medical community, by the public, by funding bodies and by regulators," says Dr Charles Grob, a professor of psychiatry with a special interest in hallucinogens, substance abuse, and mood disorders. "The taboo seems to be falling aside and there is now the opportunity to look more objectively at their range of efficacy and their safety."

But this is not just a case of necking some pills or mushrooms, and feeling a sense of calm. Patients are screened for suitability first and for the drugs to be effective, and they must be administered alongside intense therapy sessions that may last for many hours, an approach Grob calls 'augmented psychotherapy'.

"You establish rapport with the patient in several introductory, preparatory meetings then you have a treatment session, many hours long, followed by several follow-up psychotherapy sessions," says Grob. "It's very different from

In November, cannabis-based products were legalised for medicinal use

the standard pharmaceutical model where you're just taking your pills on a daily basis, sometimes for months or years on end."

Some of the most promising and advanced research has looked at psilocybin, the powerful hallucinogen found in magic mushrooms. Studies found that administering the drug to people with terminal cancer helped them cope with the overwhelming and existential anxiety of being close to death. The drug, made illegal in the UK in 2005, has also shown promise in the treatment of chronic alcoholism, and even appears to help people quit smoking.

The chemical used in ecstasy, MDMA, has been shown in many trials to be helpful for people suffering from severe, recurrent and treatment-resistant post-traumatic stress disorder. The research has shown such promise that the US Food and Drug Administration (FDA) granted the treatment "breakthrough therapy" status last year, making it easier for researchers to study.

Ketamine, currently a class B drug in the UK (and already used in medicine as an anaesthetic) is another psychedelic being investigated for its powerful effect in psychiatric therapy. It has been shown to be effective in some people with particularly hard-to-treat depression and bipolar disorder, with people reporting long-lasting relief from symptoms after just one dose. And researchers are just starting to look seriously at the effects of ayahuasca, the plant-based brew used in shamanic rituals by tribes in the Amazon basin. Again, early reports suggest that this powerful hallucinogen can help people overcome addiction and trauma.

BRAIN REBOOT

So what is it about psychedelic substances that makes them so useful in the treatment of these complex, personal mental health problems?

"There are some very interesting perspectives on something called the 'default mode mechanism' that says taking these substances is kind of like going offline and then rebooting the brain," says Grob. "The other perspective tries to understand why these substances are effective from an entirely different direction. Many individuals report having a sort of mystical experience, a psycho-spiritual epiphany. This powerful spiritual experience, in and of itself, might be predictive of a positive outcome."

The problem is, mystical or profound inner experiences are hard to study scientifically. That is made harder by the regulatory loops researchers must jump through to get the funding and licenses required to work with Schedule 1 substances. It makes them extremely difficult to study, says British neuropsychopharmacologist Prof David Nutt.

"It adds a lot of time and expense," says Nutt, who was sacked as the UK's chief drug advisor in 2009 because of his opposition to the government's drug classifications. "It increases costs by about 10 times and adds, on average, about a year of time to get studies through all the extra regulations."

Researchers like Grob are confident things will change soon: "We're living in a different culture that's more amenable to reconsideration of these compounds."

"Taking these substances is kind of like going offline and then rebooting the brain"

THE ZOMBIE DRUG

It's been blamed for an 'epidemic of zombies' on our streets, and chaos in UK prisons – but what is 'spice'?

The substance known as 'spice' is usually a mixture of dried and shredded plant material, sprayed with various synthetic chemicals meant to mimic the main component of cannabis, THC. These chemicals, when smoked, act on a key part of the central nervous system that regulates mood, pain-sensation, appetite and memory.

Spice and other types of 'synthetic cannabis' produce much more intense and long-lasting effects than THC, and because of the variation in the compounds and bulking agents used, are much more unpredictable.

Videos of spice users often show them in trance-like states, staggering around or convulsing – hence why newspapers are calling it the 'zombie drug'. It can also be highly addictive and cause breathing difficulties, panic attacks and psychotic episodes.

Various brands of similar drugs were known as 'legal highs' before being banned in 2009. Despite the ban, authorities have struggled to keep track as new types of synthetic cannabinoids come onto the market.

As a result, 'spice' and variations of it are still easily available in the UK, and their use is a particular problem in prisons and among vulnerable groups.

GETTY, SHUTTERSTOCK

THE BOY IN PINK

Gender stereotypes affect child development. But are we on the brink of a backlash?

WORDS: **HAYLEY BENNETT**

BBC TWO

Watch clips from *No More Boys and Girls: Can Our Kids Go Gender Free?* bbc.in/2qjhZFq

A girl who turns up to school dressed head-to-toe in pink will probably pass unnoticed. If a boy does the same, he will inevitably face stares and potentially taunts. Even the most non-traditional parent would think twice about exposing their son to that. Yet science shows that submitting to gender stereotypes has negative effects on our children – on their behaviours and attitudes as they grow into adults. In the next few years, the impacts on brain development will emerge too.

Children start paying attention to gender differences much earlier than some parents realise, according to psychologist Christia Spears Brown, the author of *Parenting Beyond Pink and Blue*. "Society emphasises that gender is important really early in a kid's life," she says. "We label it a lot in our language – we use gender as nouns all the time. So we frequently say 'oh, there's that girl' or 'come on boys, let's go get in the car.'" Research suggests children's recognition of gender is more due to adults pointing it out than any innate awareness of it.

GETTY

Toys with a science, tech, engineering or maths focus were three times more likely to be targeted at boys

At the same time, children start seeing the roles their parents inhabit in the household as typical 'mum' and 'dad' roles, and learning that toys and clothes are divided into pink for girls and blue for boys. While 2016 research by the Institute for Engineering and Technology found that some online retailers are phasing out the labelling of toys for 'girls' and 'boys', some researchers claim toys are more gendered than they were half a century ago. In the IET study, nine out of 10 girls' toys were pink and toys with a science, technology, engineering or maths focus were three times more likely to be targeted at boys.

What's concerning about this is that toys aren't really "just toys", says Brown. The skills children learn through play actually shape their development. In the next few years, she predicts, brain-scanning studies will start to help us understand how these early experiences shape neural development, leading to sex differences.

So how can parents rally against traditional gender roles? We can make smarter choices about toys – that's the easy part – but we also have to model non-stereotypical behaviour in our parenting, for example, showing that dads cook, clean and do school drop-offs too. Rather than pretending the stereotypes don't exist, Brown advises we teach our children about them and how to recognise them. "So if a boy chooses to wear the pink shirt," she says, "he's also equipped to talk to other people about what gender stereotypes are."

VR HELPS SPOT SUICIDAL TENDENCIES

Virtual reality and machine learning are being used to spot the signs that someone might want to end their life

WORDS: **SIMON CROMPTON**

Official records say that in the UK in 2016, 4,508 men and 1,457 women died as a result of suicide, but some experts believe the true number may be double that. Men appear particularly vulnerable: in fact, suicide is the leading cause of death in men under 50 in the UK, claiming more lives than car accidents, heart disease or cancer.

The reasons so many men take their lives are a complex web of social, psychological, biological and cultural pressures. But new scientific approaches are presenting unexpected avenues for untangling the threads. Virtual reality experiments and artificial intelligence are revealing those most at risk, and presenting the prospect of predicting who is likely to try and take their life. Together, they present the prospect of better prevention.

STEPPING INTO A VIRTUAL WORLD

According to Prof Rory O'Connor, who runs the Suicidal Behaviour Research Lab at the University of Glasgow, changes in society are making men especially prone to feelings of entrapment that seem to be a key driver to suicide. His lab works with suicide survivors and conducts studies to find links between suicide and psychological and social characteristics.

Proving such links is not easy. But American psychologist Dr Joe Franklin, who heads the Technology and Psychopathology Lab at Florida State University believes he may have found an answer by probing the causes of suicide using virtual reality and a form of artificial intelligence called machine learning.

Franklin's team exposed their test subjects to standard psychological scenarios designed to make them feel mildly socially rejected. Then they put them into a virtual reality scenario in which they're standing on top of a high building. Some of those who had been socially rejected chose to jump.

There are potentially thousands of factors that contribute to suicide. But the only way of sorting out which of those factors is significant is by using machine learning.

"You give the machine every bit of information you have," says Franklin. "You say: we have 500 people who died of suicide, another 500 who didn't. Here's 2,000 bits of information about them all. Now sort out the best algorithm for pulling those groups apart." This system could be plugged into national electronic health records to find patterns of contributing factors and to identify individuals' suicide risk.

CHOKE POINTS

Amid the complexity, the data from virtual reality experiments and machine learning is likely to reveal psychological 'choke points', says Franklin, where preventative action may work on many fronts. There's already evidence about the effectiveness of some public health choke point initiatives, effectively making it harder to commit suicide. The number of paracetamol overdoses in the UK fell significantly when a limit was placed on the number of tablets each customer was permitted to buy.

Investigating how the latest tech can be used to identify those most at risk will be at the top of the to-do list for Conservative MP Jackie Doyle-Price in 2019. As the newly appointed minister for suicide prevention, she is leading the government's efforts to cut the number of suicides and overcome the stigma that stops people seeking help.

SUICIDE STATISTICS

878
male students took their lives between 2001 and 2017 (England and Wales)

45%
of trans young people have tried to take their lives (UK)

12
men kill themselves every day (UK)

3 in 4
suicides are by men (UK)

HOW TO FIND HELP

- Samaritans is a safe place for anyone to talk about difficult feelings, 24 hours a day. Phone free (UK/ROI) on 116 123 or email jo@samaritans.org
- The CALM helpline is for men in the UK who need to talk or find information and support. Open 5pm until midnight 0800 58 58 58

ILLUSTRATION: OWEN GENT

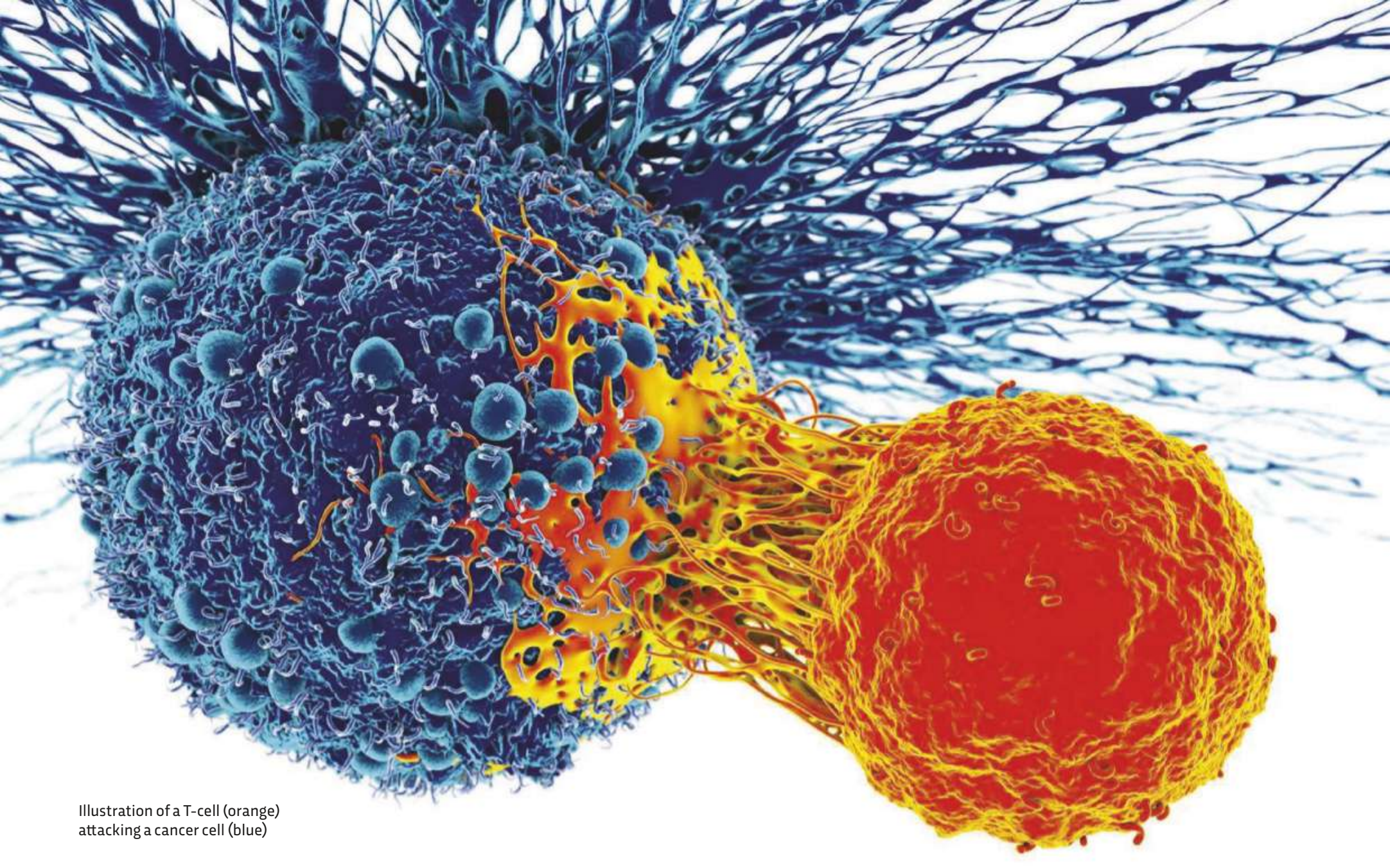


Illustration of a T-cell (orange) attacking a cancer cell (blue)

IS A CANCER VACCINE ON THE HORIZON?

For years immunotherapy has held huge promise. Finally, it seems to be coming to fruition with hopes for a cancer vaccine in the near future…

WORDS: **TOM IRELAND**

The idea of using patients' own immune cells to fight cancer is over a hundred years old. In the late 19th century, an American doctor called William Coley attempted to treat cancer by stimulating the immune system with dangerous bacteria, arguably the first example of what is now known as immunotherapy. His procedure appeared to shrink some patients' tumours, but was criticised as unsafe and largely forgotten about. Chemotherapy and radiotherapy became the focus of cancer research and the standard tumour treatment for the rest of the 20th century.

Now, however, immunotherapy is at the forefront of cancer research again.

Our immune system is constantly detecting and destroying infected or defective cells in order to keep us healthy. When defective cells somehow evade this system and start to multiply in the body, we call that cancer. Cancer cells

GETTY; ALAMY

make it difficult for the immune system to work in many ways – they hide their tell-tale proteins, disguise themselves as healthy cells, and release chemical signals to slow down the immune system. Once cancer cells have grown into a tumour, it then becomes physically difficult for immune cells to penetrate and act within this hostile microenvironment.

Drugs made from antibodies, which help the immune system target cancerous cells, have been in use since the late 1990s. More recently, substances have been developed which turn off the chemical signals that tumours release to dampen the immune system.

Last year, a handful of exciting new treatments were approved for use which are made from patients' own modified immune cells instead of toxic chemicals. Known as CAR T-cell therapies, these treatments involve extracting immune cells from the patient, genetically modifying them to express molecules found on the surface of the cancer, then injecting millions of them back into the patient's blood stream. These special cells, known as T-cells, then help orchestrate an immune system attack on the cancer cells en masse.

THE HOLY GRAIL

But the elusive holy grail of cancer immunotherapy is the so-called 'cancer vaccine'. The idea here is to 'teach' the immune system to attack cancer cells in the same way a vaccination teaches the immune system how to recognise and deal with a certain virus. Not only would this help the body destroy a tumour, but it should help the immune system detect and neutralise any similar cancer cells that return in future.

Yet despite decades of research, cancer vaccines are only just starting to show promise in clinical trials. The therapies involve presenting the immune system with a chemical fragment of the tumour, just like when a weakened version of a virus or bacteria is presented to the body in a conventional vaccination. Finding a suitable molecular fragment from the tumour that will provoke a powerful but safe immune response (known as an antigen) has proven difficult.

Firstly, it must be an antigen not found anywhere else in the body, or the immune system could start to attack healthy cells. This

Cancer cells hide tell-tale proteins, disguise themselves as healthy cells, and release signals to slow down the immune system

At the Fraunhofer Institute in Germany, biochemist Christin Meißner (right) and medical technical assistant Andreas Kirschner analyse cells for a new form of cancer therapy

immediately rules out around 95 per cent of tumour antigens. Even once a suitable, tumour-specific antigen is found, there's no guarantee the immune system will react to it. After all, for the tumour to have grown, the cancerous cells and all their proteins must already be successfully evading the immune response somehow. Cancerous cells and tumours often release substances that prevent the immune system from working properly.

A new approach is to combine cancer vaccines with other substances that block cancer's ability to manipulate and evade the immune system. These results have been much more promising, and experts believe this combination therapy will lead to a stream of cancer vaccines approved for use in 2019 and beyond.

"Our ideas about the design of cancer vaccines have changed," says Haval Shirwan, a cancer immunotherapy expert and professor of immunology at the University of Louisville.

Labs are developing vaccinations to treat lung cancer by stimulating the immune system to recognise and attack cancer cells

"Using the right antigen alone is not enough: you have to also have a substance that helps the immune system overcome the evasive mechanisms that are stopping it from fighting the cancer itself."

These substances are known as checkpoint inhibitors. They block the chemical signals that normally act as brakes on the immune system, but can be used by cancer to suppress the immune response around a tumour. Checkpoint inhibitors hold a lot of potential. Indeed, the 2018 Nobel Prize in Physiology or Medicine was awarded to Dr James Allison and Dr Tasuku Honjo for their work on them.

"After a period of great doubt [about cancer vaccines], there is a great deal of excitement again," says Christian Ottensmeier, professor of experimental cancer medicine at the University of Southampton. He says cancer researchers now better understand how to 'package' cancer vaccines so that the immune system recognises the key antigen as a danger, provoking immune cells to mount an attack. "It's all about the tricks you use to make your antigen interesting to the immune system," he says, suggesting cancer vaccines packaged within viruses, or even based on whole tumour cells, may be more effective.

Despite the progress being made, there is still much more to learn about how different people's genetic make-up affects how they will respond to different treatments. In the future, powerful algorithms could help doctors quickly determine which antigen from an individual tumour is the most likely to provoke an effective immune response, and which are the best combinations of additional immune system boosters for that particular patient.

"A genome could be sequenced and an analysis done on the likelihood of an individual developing a disease, before it happens"

TARGETING AUTOIMMUNE DISORDERS

The revolution in our understanding of the immune system is also helping researchers develop treatments for other diseases, too. In autoimmune disorders, the immune system mistakenly attacks healthy cells, causing chronic ill health. Here, researchers aim to do almost the exact opposite of cancer immunotherapy: instead of boosting immune system cells aiming for a specific target, they want to dampen down or switch off immune cells that are mistakenly attacking a target in the body.

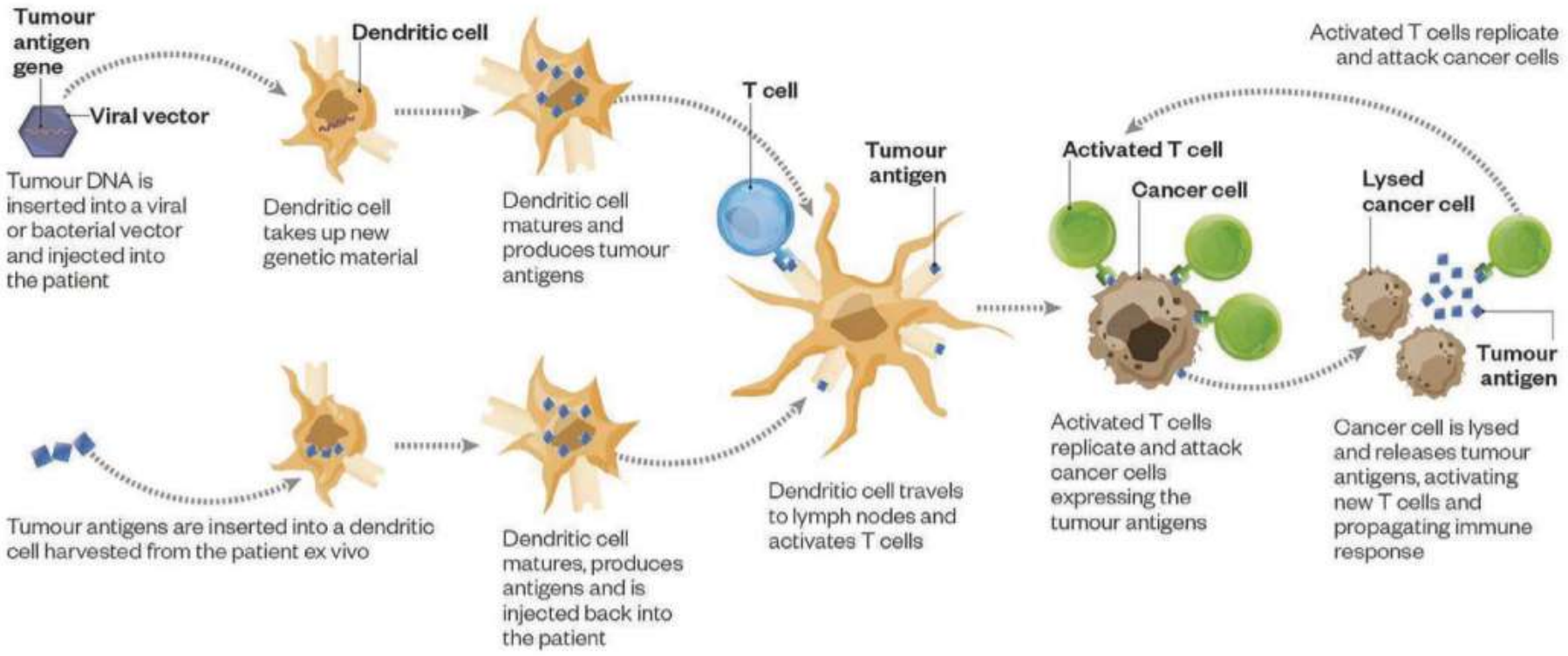
Common autoimmune diseases include type 1 diabetes (caused by the immune system destroying insulin-producing cells), rheumatoid arthritis (caused by an inflammatory immune response in the joints) and multiple sclerosis (caused by immune system-related damage to the protective coating of nerves).

Until now, these diseases have been treated by just trying to provide relief from the symptoms or by dampening the whole immune system, which makes patients vulnerable to other disease and infection. A new approach is to identify the specific immune cells that are mistakenly attacking antigens in the body, and teach them that the molecules they think are dangerous are not.

"The approach is similar to the immunotherapies that have been used to 'desensitise' people to allergens," says Professor David C Wraith, director of the Institute of Immunology and Immunotherapy at Birmingham University. He

GETTY. ROYAL PHARMACEUTICAL SOCIETY

HOW CANCER VACCINES WORK



Cancer vaccines aim to 'teach' the immune system to attack and break down tumours. First, a molecule must be found that is expressed exclusively by the cancer cells, known as an antigen. Then the body's immune cells must be encouraged to attack any cell found to have that antigen. Immune cells known as dendritic cells are key to cancer vaccines, as they 'present' antigens of interest to the other immune cells, effectively telling them which antigens to find and attack.

Dendritic cells can be 'educated' to recognise tumour-specific molecules, either within the body or by growing them with the tumour molecules in the lab. The key is finding the right tumour molecule, and presenting it in a way that makes it interesting to the immune system.

The matured dendritic cells then present the key molecule to the immune system, stimulating T-cells to attack the tumour. Substances to boost the activity of the immune systems, known as checkpoint inhibitors, prevent the tumour from releasing signals that block immune system activity.

believes these 'antigen-specific' therapies for autoimmune diseases could be rolled out in around five years. They could even be used to prevent these diseases ever developing in people who are genetically at risk.

"You can imagine a day when everybody's genome is sequenced and you can do a risk-benefit analysis of the likelihood of an individual developing an autoimmune disease, before it happens. Then you actually start to treat them with this kind of desensitising approach."

The immune system is so central to our health, that there are many more areas where immunotherapy might be used in medicine further down the line. All inflammation is caused by the body's immune response, and is often central to common conditions such as arthritis, stroke and bowel disorders. Some even believe disorders such as depression could be caused by inflammation, or that ageing is simply a problem of the immune system. These may well be the next frontiers in immunotherapy.

Sadly, the biggest barrier preventing immunotherapies from becoming commonplace in medicine might be the cost. The most effective treatments involve removing, testing and modifying individual patients' own tissues and cells, a very different model to traditional therapies based on chemicals that could be mass-produced. Some experts believe this is not something health systems can afford to do.

"It's an existential crisis for medicine, a great problem looming for society," says Dan Davis, professor of immunology at Manchester University and author of *The Beautiful Cure: Harnessing Your Body's Natural Defences*. "The more complicated and expensive the treatment, the harder it will become to reduce health inequalities and have an affordable care system."

BBC RADIO 4

Listen to Adam Rutherford discuss cancer immunotherapy
bbc.in/2Sv8PCk

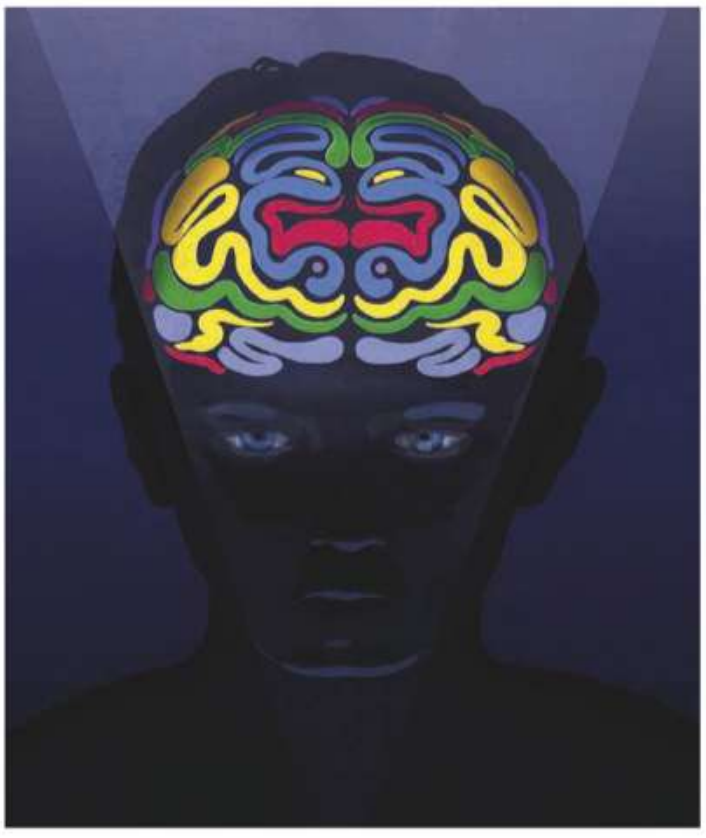
NEW TECH FOR AUTISM

A clever device that scans biometric data could help patients that are on the spectrum

WORDS: **PAUL PARSONS**

Autism is a lifelong developmental condition characterised by difficulties with language and social interaction, and a tendency for repetitive behaviours. It is a spectrum condition, meaning that its symptoms and their severity vary greatly from one individual to the next. Those who experience autism range from the high functioning, such as naturalist and television presenter Chris Packham, through to people for whom it's a profound disability, precluding the possibility of an independent life.

The US Centers for Disease Control and Prevention estimate the autism prevalence to be 1 in 59 children, with approximately five times more males being diagnosed than females. In the UK, the rate is thought to be around 1 in 100.



In the coming years this technology may combine with the Internet of Things to enable automated safeguards

FIGHT OR FLIGHT

It has emerged that many autistic people process sensory information differently – to the point that some sensations, loud sounds, for example, can cause pain. The frustration of not being able to communicate their predicament to others, or to regulate the resulting emotional distress, can lead to a state of extreme anxiety, known colloquially as a meltdown. It's not naughtiness and it's not a tantrum. It's a fight-or-flight response to a state of severe distress – the same distress you or I might experience if our lives were in danger.

So imagine if caregivers could receive a notification to their mobile phone the instant a child's anxiety levels begin to rise. Researchers at Northeastern University, Maine Medical Centre and the University of Pittsburgh are developing just such a system. It works using a wristband, rather like a sports watch, that monitors biometric data (literally meaning 'body measurements') – specifically, the wearer's heartbeat, skin temperature, sweat levels and acceleration. The latter is important in autistic people, who often flap their arms as a way to emotionally regulate themselves (one of a group of behaviours known as 'stimming').

The wristband is being trialled at a residential care facility for autistic people. Video and audio monitoring equipment has also been installed at the facility, as well as devices to record light levels, ambient temperature, humidity and barometric pressure.

The hope is that all this extra data will not just help predict meltdowns, but also assist in understanding how an autistic person's immediate environment can exacerbate their condition. And that could help architects design new residential homes tailored to people on the autistic spectrum, and to consider the needs of the autistic individual when designing other buildings, such as shops and cinemas.

In the coming years, this technology may combine with the Internet of Things to enable automated safeguards in the care of those on the autism spectrum. For people on this spectrum – who may lack the language skills to express how they're feeling or who are often intellectually impaired – the benefits could be even more profound.

ILLUSTRATION: SAM FALCONER

The new facility at Manchester's Christie Hospital

THE CHRISTIE NHS FOUNDATION TRUST

TARGETED MEDICINE

The new particle accelerators fighting cancer

WORDS: **ROB BANINO**

Particle accelerators aren't just for spotting the Higgs Boson, they can also be used to fight cancer, like the one installed in Manchester's Christie Hospital this year. Christie's particle accelerator will be delivering high-energy proton beam therapy, a more precise form of radiotherapy that's less damaging to the healthy tissue surrounding the tumour.

Proton beams are smaller than X-rays and gamma rays used in traditional radiotherapy, and almost all of their energy is focused at the tip of the beam, rather than along its entire length. So they're better suited to treating cancers in hard to reach places, such as in the brain or spine, or in young children whose organs are still growing.

Proton beam therapy is already available in Switzerland and the US, as well as some private clinics in the UK, but Christie Hospital will be the first to provide it on the NHS. A similar unit is under development at London's University College Hospital and set to open in 2020.

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"In 2019, there will be more discoveries of exoplanets and new ideas on how these 'other worlds' formed, and how to assess whether any of them harbour life."

PROF MARTIN REES
Astronomer Royal and Emeritus Professor of Cosmology and Astrophysics at the University of Cambridge

"Following the recent launch of the European/Japanese BepiColombo mission, in 2019 our team will be keeping an eye on its progress and looking forward to 2025 as it explores Mercury."

DR SUZIE IMBER
Associate Professor of Planetary Science at the University of Leicester, who won the BBC TWO series Astronauts: Do you have what it takes?

"Commercial spaceflight will be big news in 2019, for human spaceflight as well as ISS supplies, along with a Chinese lunar landing of a robot as a precursor to a human mission to the Moon."

HELEN SHARMAN
CMG OBE, the first British astronaut (MIR Space Station, 1991, Soyuz TM-12 Soyuz)

SPACE IN 2019

GETTY

GETTY

THE RACE TO DODGE AN ASTEROID

Practising smashing a satellite into a large space rock could one day save Planet Earth

WORDS: **ELIZABETH PEARSON**

News flash: We've found an asteroid bigger than the one that killed the dinosaurs and it's heading straight for us! Thankfully, this scenario is yet to play out beyond films and TV. But the threat of an asteroid impacting Earth is very real.

Around 66 million years ago, an asteroid impact blasted enough soot into the atmosphere to cause extreme global cooling, wiping out 75 per cent of all life on Earth, including the dinosaurs. It's only a matter of time before another huge space rock is destined for a high-speed date with our planet.

But a giant meteor flying straight towards Earth might not be as fatal as it was 66 million years ago. As science fiction author Larry Niven once said, "The dinosaurs are extinct because they didn't have a space programme." We do.

The world's space agencies are finally rising to the challenge to protect humanity from the fate of our Cretaceous ancestors by mounting a mission that could give us the skills we need to change the course of a killer space rock – the Asteroid Intercept and Deflection Assessment (AIDA), the first ever attempt to change the course of an asteroid.

The mission starts in 2021, when NASA launches the Double Asteroid Redirection Test (DART), a spacecraft with a seemingly simple task in mind.

"We're going to take a spacecraft which is around 100kg in mass and ram it into the moon of an asteroid," says Andy Rivkin of the Johns Hopkins University. "Then we're going to see what the effect of our ramming it is."

The orbit of asteroid Didymos brings it within a mere 10 million km of Earth. In space terms, that's right next door. DART's actual target is the 170km space rock in orbit around it, nicknamed 'Didymoon'. And by target, NASA means just that. DART will take aim, and smash directly into the moon.

"We're going straight in," says Rivkin. "There's no orbit. We get one shot."

This high-speed crash should speed up Didymoon's velocity by a few millimetres per second. It's a tiny amount, but it is enough to change the moon's orbit. With enough time, a similar technique – known as 'kinetic impactor' – could one day be used to change the path of an Earth-threatening asteroid so that it dodges past our planet.

After DART's crash, NASA will watch Didymoon to see if the time it takes to orbit (currently 11.9 hours) gets any shorter. Seeing this change will not only tell the researchers that the mission was successful, but how successful it was. It is one

thing to be able to change an asteroid's orbit, it's another to be able to predict how much it will change by.

It is this predictive ability that the second stage of the mission will look into. Just before impact, DART will launch a cubesat made by the Italian Space Agency. The cereal box-sized spacecraft, nicknamed 'SelfiSat', will watch the impact, taking pictures of the crash site to help geologists understand exactly what effect DART has had on the moon.

We won't get a detailed view of what happened, though, until 2026 when the European Space Agency's Hera spacecraft enters into orbit around Didymos and gets to know both main asteroid and moon in incredible detail.

"We need to get a precise measurement of the mass of this little moon," says Ian Carnelli, the manager of the Hera mission.

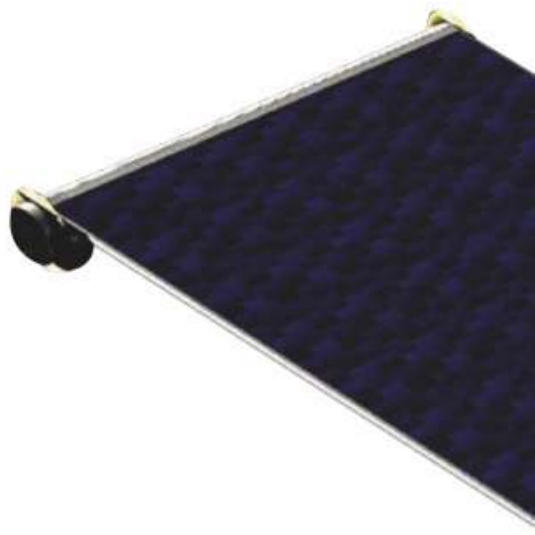
Knowing the mass is vital as it tells us exactly how big of a speed change we would expect to see from DART's crash landing. But it will take more than that to fully understand the DART impact.

"We'll get a measure of the surface roughness, whether there are boulders on the surface, whether the interior structure has some voids. Because all of these affect the deflection," says Carnelli.

This is vital to fine-tune the forecasting software researchers would use should we ever need to mount a real mission against an extinction level impact. By the end of AIDA we should not only know whether it is possible for us to deflect an asteroid, but be able to predict where we would be sending it.

"Asteroids are the only natural threat that we can predict, but also prevent," says Carnelli. "When kinetic impactor is validated, then we really retire the risk of an asteroid impacting the Earth."

It has taken 66 million years, but planet Earth is finally ready to take out an insurance policy against the threat of killer asteroids.



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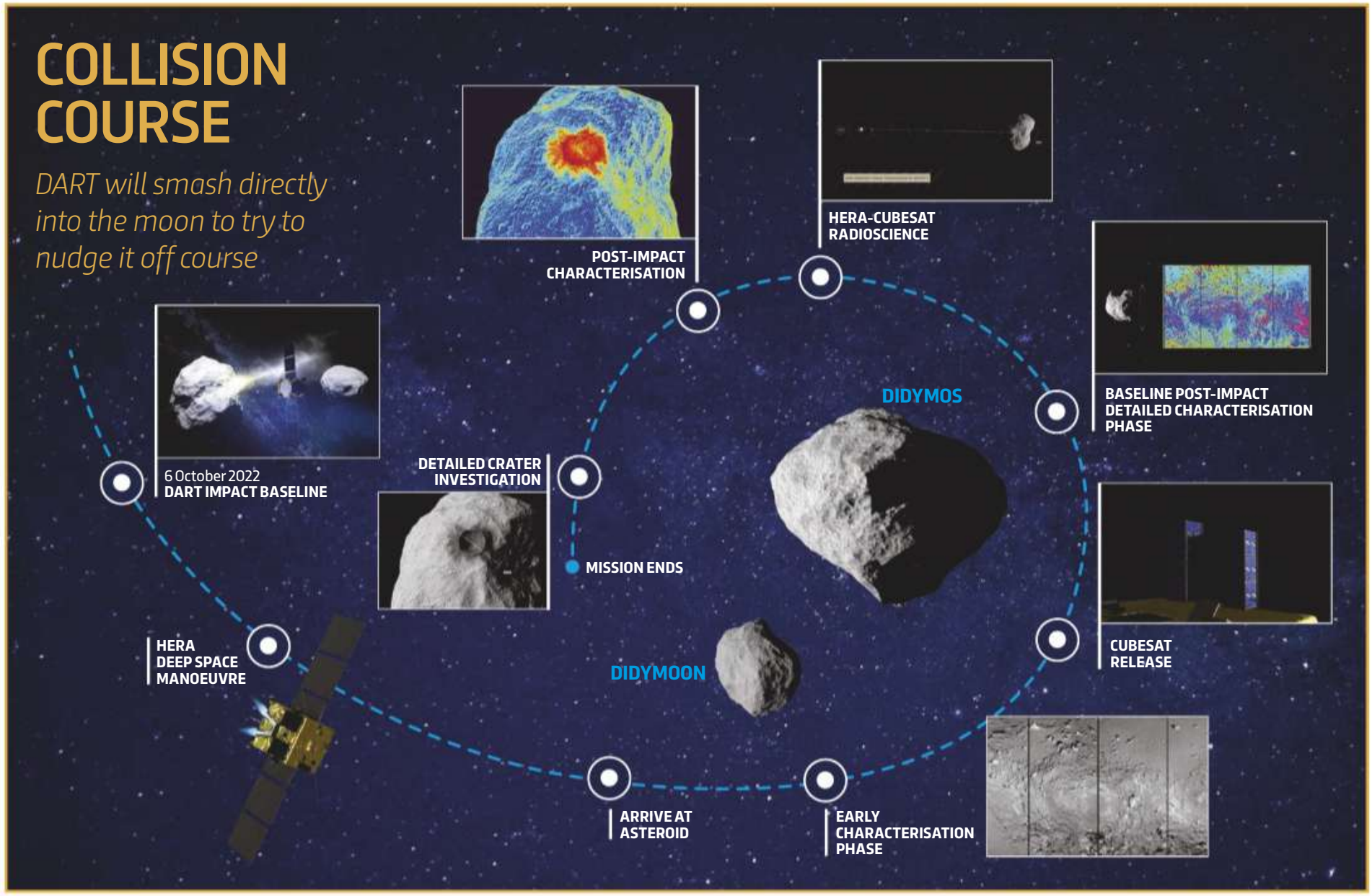
COLLISION COURSE

DART will smash directly into the moon to try to nudge it off course



ESA, NASA/JHUAPL

HOW TO SAVE EARTH

To dodge an asteroid follow these three easy steps...

1 Search

We can't deflect an asteroid unless we know it's coming. Telescope surveys already scan the sky searching for potentially hazardous space rocks, and we think we know the location of over 90 per cent of extinction level asteroids, but one even a few dozen metres across could cause serious damage.

2 Characterisation

Once we know an asteroid is coming, we need to know what it's like. Size, shape, composition and density all have an effect on how dangerous an asteroid is, but also how we can deal with it. A heavy asteroid would take more mass to stop, while a low density one might break apart.

3 Mitigation

If we know about an asteroid a decade in advance, we can give it a gentle nudge using a similar technique to the DART mission. Over several years, a small change in course would be enough to avoid the Earth. However, if we don't get enough warning, more drastic measures may have to be taken, such as using a nuclear bomb's shockwave.

CATCHING A WAVE

In 2019, we should detect a new type of gravitational wave

WORDS: **MARCUS CHOWN**

Gravitational waves are ripples in the fabric of spacetime, as predicted by Einstein in 1916. So far, researchers have picked up 'bursts' from the mergers of black holes or super-dense 'neutron stars'. But it's hoped that next year we'll spot the first 'continuous' source from an isolated neutron star or even a burst from a supernova.

The first signal was detected on 14 September 2015 by the two giant detectors of the Laser Interferometric Gravitational-wave Observatory (LIGO). The short burst came from the merger of two monster black holes 1.3 billion lightyears away, which pumped out 50 times more power than all stars in the Universe combined.

The two American detectors have now been joined by the European Virgo detector and have so far picked up the merger of several binary systems composed of black holes and one composed of neutron stars – Mount Everest-sized relics of supernovae so dense a sugar-cube-sized volume of their material would weigh as much as the whole human race.

Gravitational waves are produced by any acceleration of mass that is not spherically symmetric. Both a black hole merger and a neutron star merger fit the bill. So too does a black hole swallowing a neutron star, another event that may be detected in 2019. But another hope is that we will detect isolated neutron stars in the guise of 'pulsars' – fast spinning, radio-wave emitting neutron stars. If they are non-spherical with even a 10-centimetre-high mountain on their surface, they should generate not a burst but a continuous gravitational signal rather like a pure musical note.

"The chances of seeing a pulsar in the coming few years are quite good," says physicist Prof Ken Strain of the University of Glasgow.

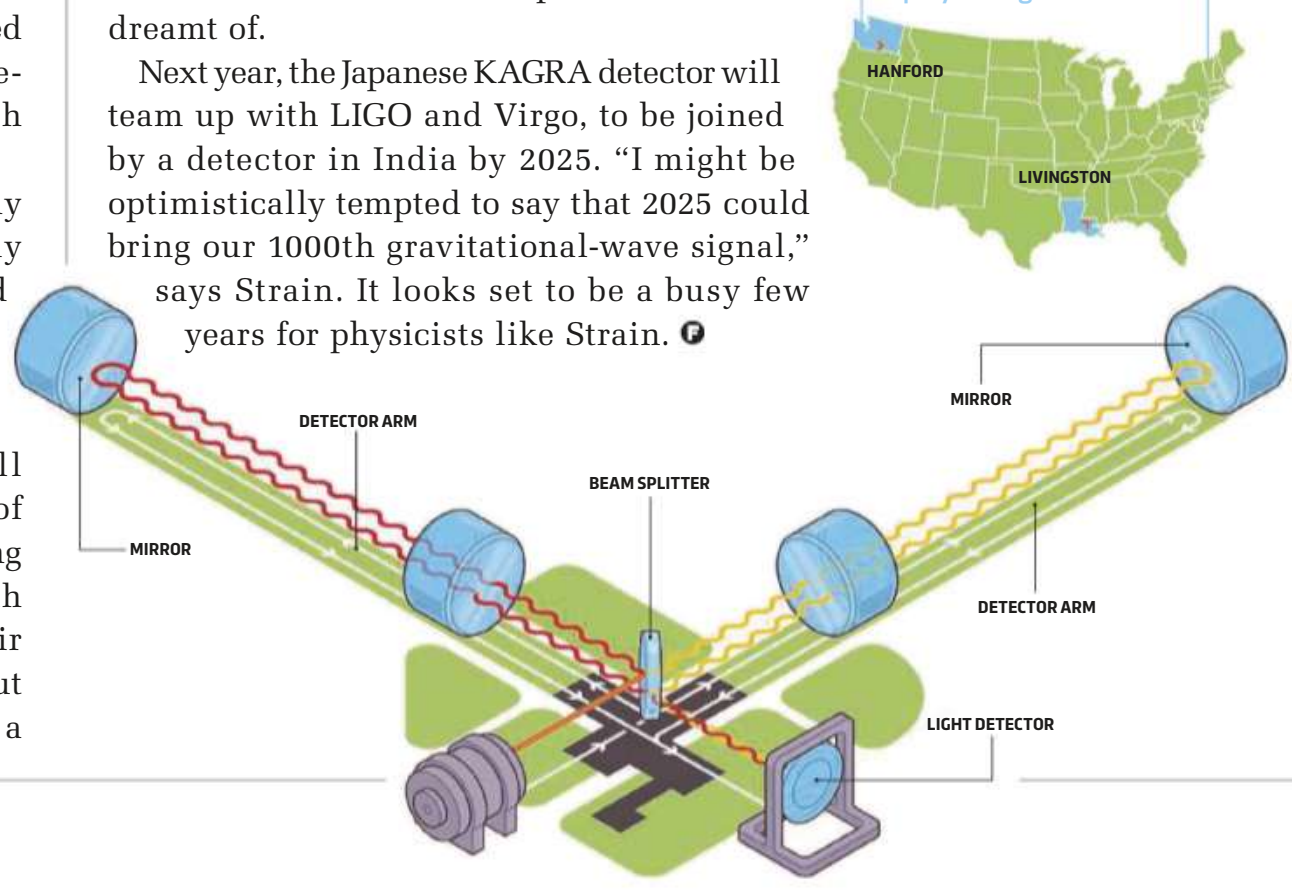
Another aim is to detect a burst of gravitational waves from a supernova in our galaxy. A supernova occurs about once every 30 years in the Milky Way, so we will have to be lucky. Or maybe we'll pick up gravitational waves from a source never before predicted or even dreamt of.

Next year, the Japanese KAGRA detector will team up with LIGO and Virgo, to be joined by a detector in India by 2025. "I might be optimistically tempted to say that 2025 could bring our 1000th gravitational-wave signal," says Strain. It looks set to be a busy few years for physicists like Strain.

The Virgo Observatory, located near Pisa, Italy, detected a transient gravitational-wave signal produced by the coalescence of two stellar black holes

THE LIGO EXPERIMENT

There are two LIGO observatories, which are located 3,002km apart. Each LIGO observatory consists of a laser source, two detector arms – each with a mirror at the end – and a light detector. The laser shines onto a beam splitter and is sent down the detector arms, which each measure precisely 4km in length. At the end of the arms, the light bounces off the mirrors. If light waves fall out of sync due to being affected by gravitational waves, then this will be picked up by the light detector.



THE VIRGO COLLABORATION/CCO 1.0, ILLUSTRATIONS: RAJA LOCKEY

EXPECTING THE UNEXPECTED

Surprises are in store for the New Horizons' fly by

WORDS: **MARCUS CHOWN**

There will be no New Year's Eve revelry for those working on NASA's New Horizon's space probe. They will need to be stone cold sober with their wits about them when, on New Year's Day 2019, it whizzes past one of the fossil building blocks of the planets and one of the most primitive bodies in the Solar System.

2014 MU69, now renamed Ultima Thule from a medieval term meaning 'beyond the known world', had not even been discovered when New Horizons was launched towards Pluto in 2006. Discovered by the Hubble Space Telescope in 2014, it is a member of the Kuiper Belt – a swarm of icy bodies orbiting on the edge of the Solar System that are so sparsely distributed that they never accumulated into planets.

What excites planetary scientists about Ultima Thule is that it is pristine. Whereas Pluto (which New Horizons flew past in July 2015) has an active surface, Ultima Thule is expected to have remained unchanged since the birth of the Solar System 4.55 billion years ago, and therefore promises to tell us about the bodies that came together to make Pluto.

Ultima Thule, orbiting 1.6 billion kilometres beyond Pluto, or 43 times further from the Sun than the Earth, is believed to be about 32 kilometres wide.

"It's less than one per cent of the size of Pluto and can't sustain an atmosphere," says Marc Buie, a member of the New Horizons science team. "It will be completely different."

On 1 January, when New Horizons flies within 3,500 kilometres of Ultima Thule, it will be the most distant object ever imaged in the Solar System. It should be possible to see features as small as a basketball court.

Pluto proved a massive surprise. Far from being in suspended animation in the frigid wastes at the edge of the Solar System, it revealed itself to be an active world with flowing nitrogen glaciers and a possible subsurface ocean. The New Horizons' team is hoping Ultima Thule will be as unexpected a body as Pluto.

By 2025, New Horizons will be almost 4 billion kilometres further away, and heading out into the wastes of interstellar space. "We will be continuing long-range observations of other KBOs," says Buie. "Given the opportunity, New Horizons could remain busy and productive for quite a while."

BBC RADIO 4 Listen to Adam Rutherford discuss New Horizon's next mission **bbc.in/2KERsty**

NASA/JHUAPL/SWRI/STEVE GRIBBEN

THE HUNT FOR EXOPLANETS

Over the coming years, a new generation of space telescopes will seek out distant planets in the hope of unlocking the secrets of the Universe

WORDS: **IAIN TODD**

In January 1992, two radio astronomers announced a discovery that would change our view of the Universe forever. Aleksander Wolszczan had been scanning the skies to study a type of spinning star known as a pulsar, but something was blocking his view. Curiosity piqued, Wolszczan eventually discovered the root of the interference: two planets in orbit around the star. Fellow radio astronomer Dale Frail verified the data, and the pair made their incredible announcement to the world: they had discovered the first ever known extra solar planets – or 'exoplanets'.

The existence of exoplanets – planets orbiting stars other than our Sun – had long been theorised, but now there was definitive proof. For the first time, humanity could be sure that the Solar System in which it lived was not alone: there were planetary systems out there in the cosmos.

Since this discovery, there has been a concerted effort by astronomers to find even more of these exoplanets. NASA's Kepler Space Telescope, launched in 2009, has confirmed over 2,300 and revealed that, on average, there is one planet orbiting every star. The next time you look up at the night sky, think about this: for every star you can see, there is probably another world in orbit around it.

Now, a new generation of exoplanet-hunting missions is primed for follow-up investigations to build on Kepler's progress and make discoveries that could change what we know about how planets form, and how life might arise elsewhere in the Universe.

Perhaps most exciting is the James Webb Space Telescope (JWST). This orbiting observatory, due to launch in 2021, is expected to make many new discoveries, including the search for exoplanets. JWST is seen by many as the successor to the Hubble Space Telescope, albeit 100 times as powerful and, rather than orbiting Earth, will instead orbit the Sun at a distance of 1.5 million kilometres from our planet. This will help it avoid heat from the Sun, Earth and the Moon and remain cool – around -225°C. Why? Because warm objects emit infrared light, and infrared will be JWST's primary method of observing the Universe.

One of its goals will be to observe young planets forming around young stars. Stellar formation begins when clouds of gas and dust in space begin to clump mass together, growing so big that they eventually collapse under their

NASA AMES

Engineers work on the mirror of the James Webb Space Telescope (JWST)

own gravity. What remains is a young proto-star surrounded by a spinning disc of dust. Out of this dust may form a system of planets orbiting the central star, just like our own Solar System. In optical light these still-forming planets are obscured by the dust, but infrared can peer through it to get an unprecedented look at planetary formation in action.

"We build space telescopes because they can take sharper pictures, due to the fact that Earth's atmosphere is not in the way distorting what we're trying to see," says Dr Jane Rigby, one of the mission's project scientists. "If we want to study most colours of infrared light, then we need to go into space because that light cannot shine through our atmosphere."

What's really exciting is JWST's ability to split starlight, a technique known as 'spectroscopy'. By splitting the starlight that has passed through the atmosphere of an exoplanet, scientists can analyse the chemical signatures hidden within and learn much about the properties of that exoplanet – whether it has a lot of water vapour in it, for example, or other chemicals

By splitting starlight that has passed through an exoplanet's atmosphere, we can learn about its properties

that might reveal something about the processes occurring on its surface.

"For gas giants like Jupiter and Saturn around other stars, we can look at bands of methane to see whether the atmosphere has clouds or whether it is clear," says Rigby. "This is our first chance to understand in detail the atmospheres of exoplanets, and there's a lot of interest in studying rocky planets like our own."

If we are to understand how our Sun, the Earth and the other planets formed, we need to look for examples of planetary formation in action. Until relatively recently, we only had one frame of reference: our own Solar System. Now, we have a wide variety of different stars and orbiting exoplanets to choose from.

"The results of Kepler revealed that there are so many surprises," says Dr Kate Isaak,

project scientist of the European Space Agency's CHEOPS (CHaracterising ExOPlanet Satellite) mission, due to launch in early 2019. "In our Solar System we have smaller, rocky planets closer in, and large planets like Jupiter are further out. But other systems reveal hot Jupiters – huge gas giants that have orbits shorter than a few days around their host star. The geometry of the planet systems we are finding is very different from our own, and this is very exciting."

SEARCHING FOR 'SUPER EARTHS'

The key aim of CHEOPS is to carry out follow-up observations of bright stars that are already known to host exoplanets, and it will primarily be looking at a class known as 'super Earths' and 'super Neptunes' – exoplanets more massive than their namesakes, yet smaller than gas giants like Jupiter and Saturn. These are another planetary anomaly that astronomers just didn't know about before exoplanet study truly began.

CHEOPS will measure the regular dip in the brightness of a star as an exoplanet passes in front of it – known as a 'transit' – enabling scientists to decipher that planet's size, among other properties. Ground-based telescopes will then measure the mass of the exoplanet by observing how its gravitational pull causes the host star to 'wobble', and combining this measurement with CHEOPS's transit data will enable astronomers to calculate the planet's 'bulk density'.

"Once we get the bulk density we can then start to work out the structure and composition of the planets," says Isaak. "We don't have super Earths in our Solar System, so the question is "what are they?" Are they rocky planets like Earth, or are they icy like Neptune? Are we talking about water worlds or small gaseous balls? CHEOPS will provide a contribution towards understanding what these planets are, what they're made of, how they form and migrate, and ultimately the best conditions for life."

Understanding the conditions for life is one of the key aims of exoplanetary study. If we can get a picture of the variety of planets out there in the Universe, we can discover how common rocky planets like Earth are, whether these distant worlds have atmospheres, and whether they orbit in the 'habitable zone',

LIFE FINDS A WAY

The extreme conditions on many exoplanets may make them appear uninhabitable, but hardy organisms – known as extremophiles – have shown that life can survive in even the most hostile places.

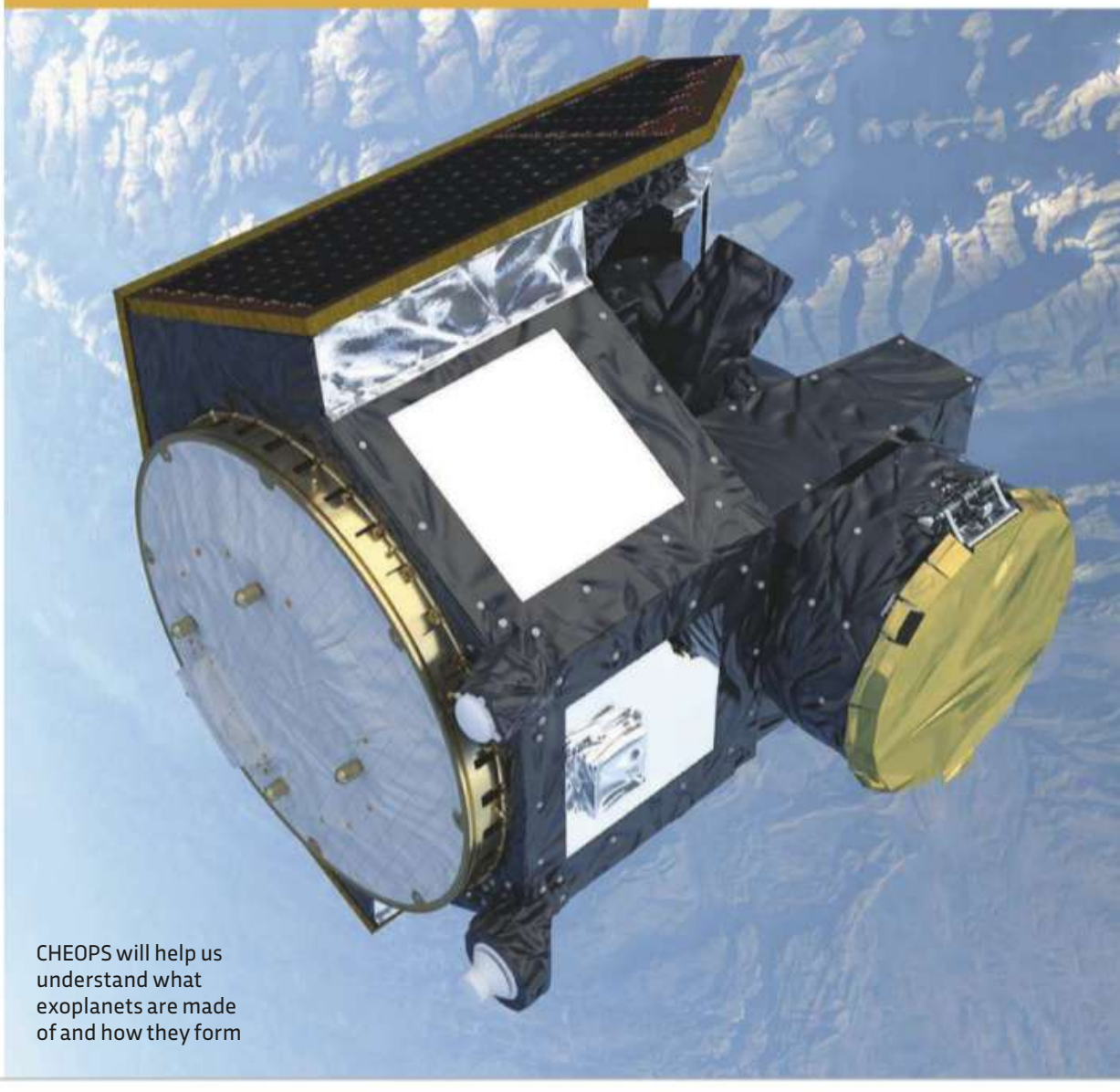
Cyanidium caldarium **is a type of algae known to thrive in hot, acidic conditions. This suggests that life might be able to survive on a planet like Venus, known for its scorching, acidic atmosphere. Meanwhile, Chroococcidiopsis is a bacterium found in hot, arid and super salty conditions. Crucially, it can survive radiation, meaning life could potentially survive on planets unshielded from the radiation of their host stars. Microbes have even been found beneath glaciers in Antarctica – cut off from light and oxygen. Could similar organisms be trapped beneath the polar ice caps of Mars?**

Perhaps most famous of all extremophiles is the tardigrade. These microscopic creatures have tolerated the extreme radiation and vacuum of space under controlled experiments by ESA. They can survive in temperatures from -272 to +150°C, and can live without water for years. What's more, if conditions become too extreme even for them, tardigrades can suspend all but their own vital functions and continue surviving in a form of suspended animation.

Extremophiles show just how robust life can be, and hint at the fact that they may be found even in the most unforgiving corners of the cosmos.

BBC RADIO 4

Listen to an episode of *In Our Time* on exoplanets
bbc.in/2RoyBqC



CHEOPS will help us understand what exoplanets are made of and how they form

NASA, ESA

in other words close enough to their star that liquid water can pool on their surface – a key condition for the survival of life as we know it.

JWST and CHEOPS will provide unprecedented studies of exoplanets, but they have to know where to look. This is where NASA's Transiting Exoplanet Survey Satellite (TESS) comes in. TESS was launched in April 2018 and has already begun its mission to monitor over 200,000 stars. It is expected to find over 1,500 potential exoplanet candidates, about 500 of which may be Earth-sized and super Earths. Its legacy should be a formidable catalogue of worlds ready to be explored by missions like JWST and CHEOPS.

ARE WE ALONE?

Since our planet is the only cosmic body we know of that harbours life, it makes sense to seek out other rocky, Earth-like worlds in the hope of discovering whether life exists elsewhere in the Universe. One space probe that will be doing just that over the coming years is PLATO, an ESA mission due to launch in 2026 that will look for small, rocky and icy bodies in the habitable zone around Sun-like stars. This, it is hoped, will enable astronomers to decipher just how common Earth-like planets are in the Universe, and where to point future missions like JWST in the hope of finding potentially habitable, rocky bodies.

"When I was a kid, we only knew about nine planets, all of them in our own Solar System," says Rigby. "We've since dropped one (Pluto), but learned about a thousand more, and one of the largest surprises is how different many of those systems are. The big question is: how did we get here? How did Earth form? How did the Sun form? How did the conditions for life, with lots of iron and nitrogen – not to mention tonnes of water – on a rocky world, come to be?"

As Wolzsczan and Frail's discovery shows, you never know when the next revolution in astronomy will be made, and curiosity is our best tool for seeking out these astronomical epiphanies. The new generation of exoplanet-hunters are just that: tools to peer out into the cosmos and study distant planets lightyears away, in the hope that we might solve some of the mysteries of our own.

GETTY

STRANGER THAN FICTION

Exoplanet-hunting has revealed an abundance of oddities that could have come straight out of a science fiction novel

55 CANCRI E orbits its star 25 times closer than Mercury orbits our Sun, creating a blistering world that reaches temperatures as high as 2,400°C.

KEPLER-16B is a planet with two suns, just like Luke Skywalker's planetary abode Tatooine in *Star Wars*.

KELT-9B is a gas giant about twice the size of Jupiter with a dayside temperature over 4,300°C, making it hotter than many stars.

WASP-12B'S scorching heat allows it to reflect almost no light, making it appear pitch black.

OGLE-2005-BLG-390LB is about five times the mass of Earth and is a rocky planet with a surface temperature of about -220°C, meaning it is probably covered with frozen oceans.

GLIESE 436B has a temperature over 300°C. But powerful gravitational forces are thought to have produced 'burning ice', compressed so it remains solid despite the extreme heat.

The rover has numerous onboard cameras – some to help it land, others to help it drive around. The long arm lets the rover work like a geologist – holding and using science tools with its 'hand', known as a turret

LIFE ON MARS

NASA is sending another rover to search for signs of life

WORDS: **ELIZABETH PEARSON**

The hunt for life on Mars is on again. NASA's fifth rover, Mars 2020, will scour the Martian surface for signs that the Red Planet might once have been not only inhabitable, but inhabited.

Once the Mars 2020 rover arrives on the Martian surface in 2021, it will get to work hunting out interesting rocks. The rover is looking for those most likely to contain biosignatures – chemicals like water or hydrocarbons, which suggest that life could have existed on the Martian surface, and perhaps still does.

But rather than examining promising looking rocks in an onboard lab as its predecessor Curiosity did, Mars 2020 will create caches of samples, then leave them on the surface so a future mission will be able to retrieve the rock and return it to Earth. There, the scientists can use the world's most sophisticated laboratories to analyse every aspect of the samples searching for biosignatures. With analysis no longer limited by what can fit on a rover, it could be possible to find fossil – or perhaps even living – microbes hidden deep within the rock.

As well as searching out possible past and present life, the rover will aid in bringing future life to Mars by testing tools that could support humans on the Red Planet. Mars 2020 will test a technique to strip oxygen out of the carbon dioxide in the Martian air. Not only can astronauts use this to breathe, but it could also be used as rocket fuel.

NASA

DIVING INTO THE DEEP

2020 will see not one, but two rovers heading towards Mars. ExoMars is a joint mission between the European and Russian space agencies – both of who have tried, and failed, to land on Mars before.

Like Mars2020, ExoMars will look for signs of Martian life. But rather than scraping at the surface, it will use a 2m drill to burrow down to where any organic material would be protected from the surface radiation that would otherwise destroy it.

The rover will seek out rocks with a high water content, because on Earth where you find water, you find life. Once a sample has been drilled, the onboard laboratory will sniff out any organic molecules. While these aren't necessarily biological in origin they are the fundamental building blocks of life as we know it. Curiosity has previously found traces of organics, but ExoMars should help to pin down exactly what they are, and what they mean for potential life on Mars.

A NEW NEIGHBOUR FOR THE ISS

WORDS: **ROB BANINO**

Construction is expected to begin on China's first permanently manned space station in 2019 after successful docking and refueling tests of the Tianzhou-1 automated resupply spacecraft. The modular station will be constructed in orbit and, if all goes according to plan, is expected to be completed and hosting crews by 2022. The station's core cabin module, named Tianhe-1 and containing the guidance controls and living quarters for three crew, will be the first major element launched into low Earth orbit (between 350 and 450km above the surface of our planet) from the Wenchang Satellite Launch Centre. It will be followed by two laboratory modules in which microgravity experiments will be undertaken by the taikonauts onboard the station.

GATEWAY TO THE MOON

As the fate of the International Space Station hangs in the balance, plans for a lunar space station are being developed

The Trump administration plans to pull the plug on funding for the International Space Station (ISS) in 2025. The White House wants NASA to focus its efforts on returning to the Moon and then to Mars. As a replacement for the ISS, a new space station is being developed by NASA and other space agencies, including the European Space Agency (ESA) and Russia's Roscosmos. Gateway will orbit the Moon, making the lunar surface one short hop for astronauts. It'll enable a new wave of science experiments to probe some of the mysteries of deep space. In the longer term, it is hoped that Gateway will act as a service station for spacecraft taking astronauts to Mars and beyond.

ALAMY

A NEW EYE ON THE UNIVERSE

Astronomers are constructing a telescope spanning two continents that will reveal the Universe in unprecedented detail

WORDS: **IAIN TODD**

Ripples in spacetime, colliding black holes, the expansion of the Universe: often it's the things we don't understand that intrigue us the most. If astronomers are to have any hope of solving these mysteries, they need to build bigger telescopes.

One such telescope is the Square Kilometer Array (SKA), due to begin construction in 2020 with the first results expected in 2023. But this is a telescope with a difference. It will be made up of a number of different dishes, spread across two continents. The combined signal they receive effectively creates a single dish covering over one square kilometre of the sky. This is like two astronomers standing side by side, each with a telescope, combining their respective seeing powers to create one almighty instrument.

SKA will observe the deepest regions of the Universe using a method called radio astronomy. In contrast to the optical light observed by 'regular' telescopes, radio astronomy uses huge dishes to detect radio signals beamed out by deep-sky objects like galaxies, stars and black holes. This is why the dishes are being constructed in remote corners of Western Australia and South Africa, as well as other areas of the African continent, to avoid nuisance artificial signals created by humans.

COSMIC CONUNDRUMS

The Universe is a dusty place. Cosmic dust is everywhere; particularly in star-forming regions where the secrets of star birth and galaxy formation are waiting to be discovered. With radio telescopes, astronomers can peer through this dust and get a clearer view than they could with the human eye. And, because light from the birth of the Universe 13.8 billion years ago takes time to reach our planet, by looking deeper into space, astronomers hope to catch a glimpse of the moment the first stars ignited and spread light across the cosmos.

It is hoped that SKA will help unlock some of astronomy's most enduring mysteries, such as the magnetic fields that surround planets (including our own), stars and galaxies, and the role these forces have played in the formation and evolution of the Universe. SKA will also look at the unknown force 'dark energy' (thought to be responsible for the accelerating expansion of the cosmos), as well as gravitational waves – the ripples in space-time generated when massive cosmic objects collide (see page 36). SKA will be able to detect gravitational waves produced by the collision of behemoth objects known as supermassive black holes, potentially opening up a new way for astronomers to observe the Universe.

Much has been learned since humanity first looked up at the night sky and pondered its own existence, but there is more to discover. How did the Big Bang occur, and what was the early Universe like? How do galaxies form? Why is the Universe expanding? Projects like SKA are another step towards making sense out of the cosmic unknown. Watch this space.

SKA IN NUMBERS

2 million
The number of years it would take to play back a day's worth of SKA data on an iPod

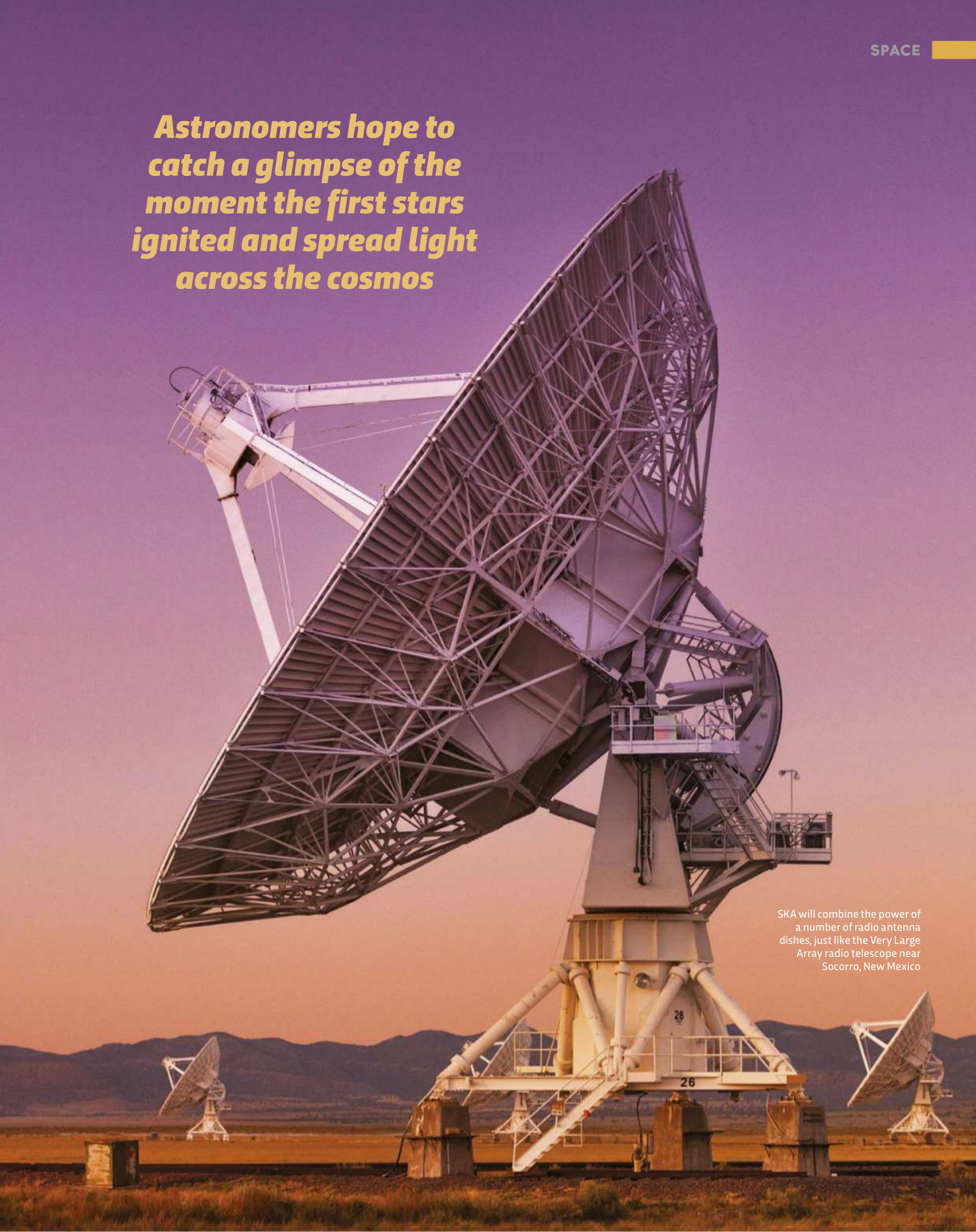
2
The number of times SKA's optical fibre cables would wrap around the Earth

100 million
How many PCs you would need to match the processing power of SKA's central computer

50
The distance in lightyears from which SKA could detect an airport radar on another planet

GETTY

Astronomers hope to catch a glimpse of the moment the first stars ignited and spread light across the cosmos



SKA will combine the power of a number of radio antenna dishes, just like the Very Large Array radio telescope near Socorro, New Mexico

BOOM OR BUST FOR EINSTEIN

Failing to find a black hole event horizon, could mean a re-think for General Relativity

WORDS: **MARCUS CHOWN**

Sometime in the next year, astronomers expect to obtain the first-ever picture of a black hole. Lurking in the dark heart of our Milky Way is the relatively large black hole, known as Sagittarius A*. The data to create the image, which has been obtained by a global network of radio telescopes, is currently being processed on a supercomputer in the US.

A black hole is a bottomless pit in the fabric of spacetime from which nothing, not even light, can escape. Nature, for a reason nobody understands, seems to have fashioned two distinct types of black holes. There are 'stellar-mass' ones, resulting from the implosion of the core of a massive star in a 'supernova'; and there are 'supermassive' ones of up 50 billion times the mass of the Sun. Nobody knows the origin of the latter kind or why there seems to be one lurking like a black widow spider in the heart of essentially every galaxy.

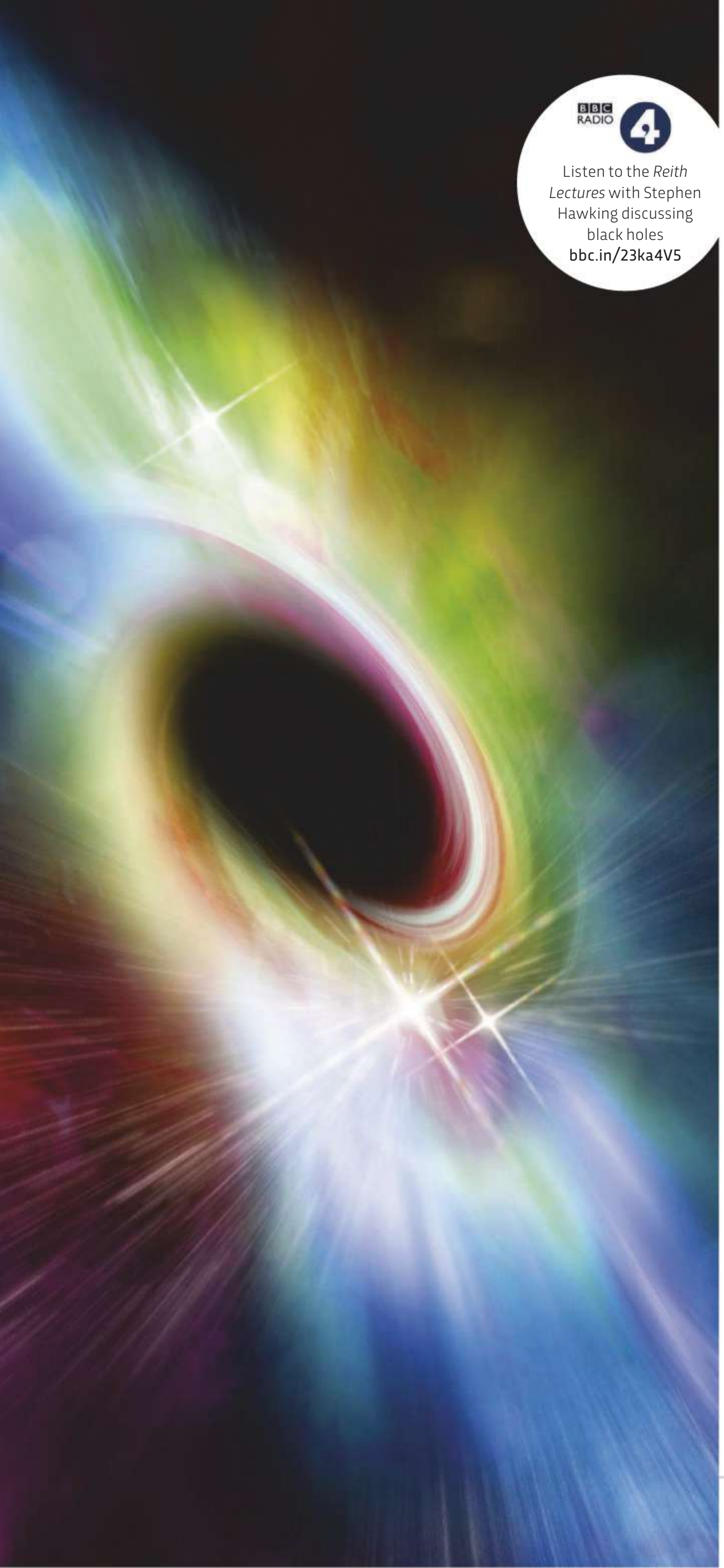
Black holes are an enormous challenge to 'see' because – obviously – they are black, and they cram their mass into the smallest possible volume of space – a 10 solar mass black hole, for instance, is a mere 60 kilometres across. Whereas supermassive black holes are much bigger than stellar mass black holes, but they suffer from the problem that they are far away and therefore also appear small. But Sagittarius A* is both big and relatively nearby – 4.3 million solar masses and 26,000 lightyears away.

Sagittarius A* is the prime target of the Event Horizon Telescope (EHT). This collection of radio dishes scattered across the globe (including one at the South Pole), combined have the same ability to zoom in on a celestial object as an Earth-sized telescope.

The EHT actually collected most of its data on Sagittarius A* during an observing run in December 2017. However, extracting an image is a long and laborious process. It involves flying data tapes from each telescope to a central computer, or 'correlator', belonging to the Massachusetts Institute of Technology (MIT).

The key thing to understand is that the individual dishes of the EHT can be considered as tiny elements of a filled-in dish the size of the Earth. But, whereas the radio waves impinging on each element of a filled-in dish are reflected to a 'focus' where they are naturally combined,

Failing to find an event horizon could point the way to a deeper and better theory than Einstein's



Listen to the *Reith Lectures* with Stephen Hawking discussing black holes
bbc.in/23ka4V5

GETTY

this does not happen for the 'elements' of the EHT. This process must be mimicked by playing back the signals on a computer and exactly reproducing the time delays there would naturally have been between them at the focal point.

Those delays have to be altered to account for such things as differing turbulence in the atmosphere above each dish. "Each time we adjust parameters in the way we combine data from across the EHT network, it takes many weeks," says the leader of the EHT team, Shep Doeleman of MIT. "You can think of this as an astronomer tweaking the focus in a single telescope to sharpen the image. Imagine if you had to wait weeks between each focus adjustment in an optical telescope in order to see if the image got sharper!"

Although the sheer volume of data is daunting, Doeleman says he and his colleagues are making good progress. "We are hoping to have first results in the first quarter of 2019."

The 'event horizon' is the imaginary membrane that cloaks a black hole and marks the point of no-return for in-falling light and matter. It is described by Einstein's theory of gravity, the general theory of relativity. Physicists know that this theory is incorrect because it predicts an infinite – and therefore nonsensical – density for the 'singularity' at the centre of a black hole. The big question is: will the EHT confirm Einstein or – and this is the most exciting possibility – fail to find an event horizon and so point the way to a deeper and better theory than Einstein's?

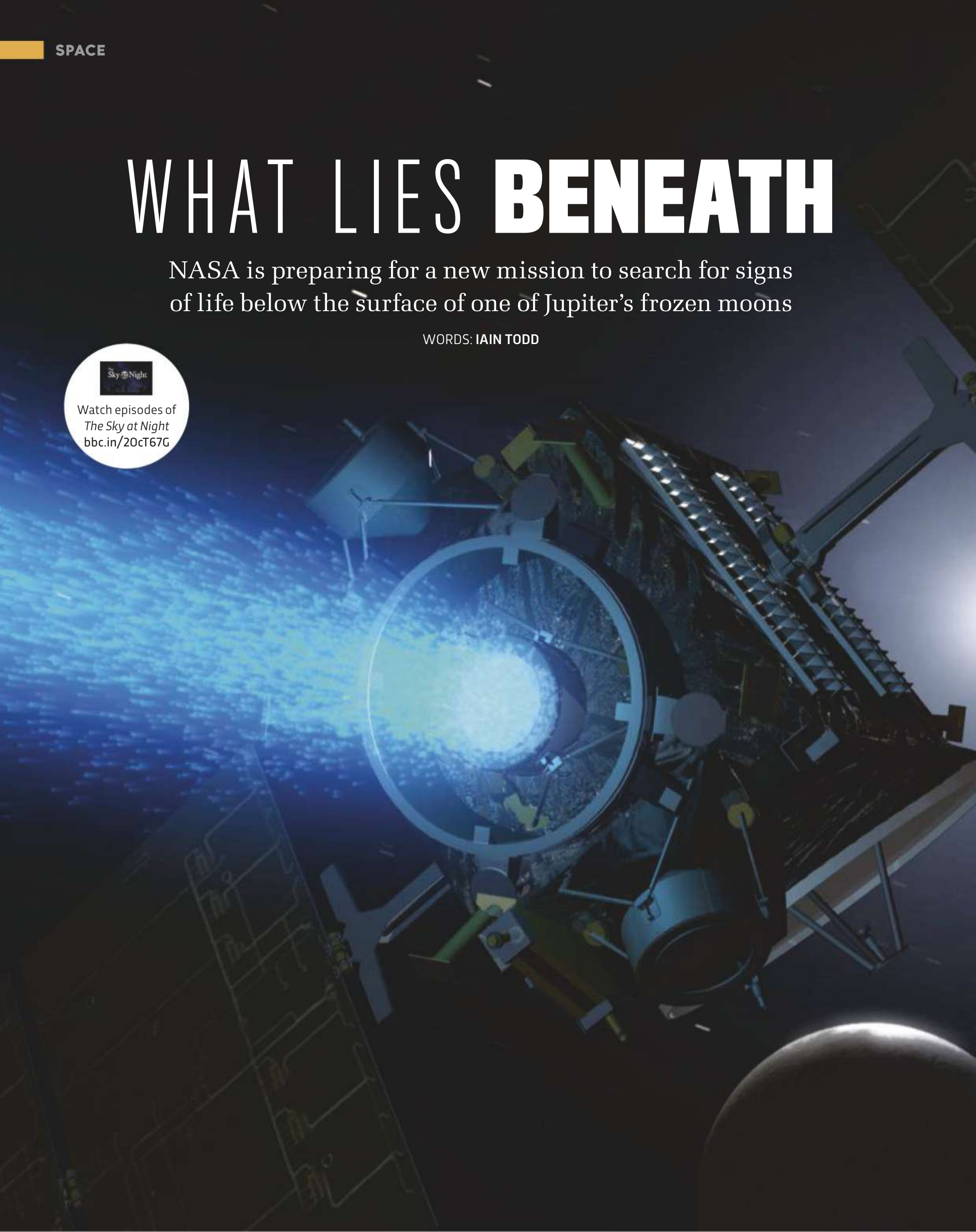
In addition to observing Sagittarius A*, the EHT is observing the supermassive black hole in the nearby 'giant elliptical galaxy', M87. Although this black hole is about 7 billion times the mass of the Sun – and therefore about 2,000 times bigger than Sagittarius A* – its greater distance of 56 million lightyears means that from the Earth it appears about half as big.

The aim of the EHT project is not simply to obtain one-off images of the supermassive black holes in the Milky Way and M87, but to monitor how these objects change. By 2025, not only should we have images of the event horizons of two black holes, but we will be able to see how they have evolved year by year.

WHAT LIES **BENEATH**

NASA is preparing for a new mission to search for signs of life below the surface of one of Jupiter's frozen moons

WORDS: **IAIN TODD**



Watch episodes of *The Sky at Night* bbc.in/2OcT67G

Europa Clipper will hunt for plumes of water vapour erupting from the lunar surface

NASA

We're living in a golden age of exploration. As humanity's unmanned spacecraft traverse the unknown corners of the Solar System, they continue to beam data back to Earth that is unravelling the secrets of the mysterious worlds that orbit our Sun.

From recent encounters like the Cassini mission around Saturn to New Horizons' close-ups of Pluto or the Juno spacecraft currently orbiting Jupiter, these odysseys have revealed the Solar System to be an active, dynamic place with stormy gas giants, volcanic moons and icy, rocky bodies.

Perhaps the grandest ambition of this exploration is the search for life. Could it be that our Solar System is entirely barren, or is there the slightest chance that some form of life is thriving beyond Earth?

SUBTERRANEAN OCEAN

One of NASA's current projects is Europa Clipper. Due for launch in 2022, the spacecraft will fly into orbit around Europa, the smallest of Jupiter's four 'Galilean' moons. This icy world is of particular interest to scientists because there is strong evidence of a salty ocean hidden beneath the planet's frozen surface. And water is a key ingredient for life as we know it.

Europa Clipper is one of many missions that will search for regions in our Solar System where even the smallest microbial life might have a chance of grasping hold. The study of so-called 'extremophiles' on Earth has revealed organisms that can survive in the harshest environments, from boiling hot or freezing cold temperatures to extreme pressures, high acidity and saturated salty solutions (see page 41). Perhaps organisms like these could inhabit a moon like Europa. It isn't a completely frozen world, after all. Its surface may be ice, but tidal flexing of the moon caused by its orbit around Jupiter could be enough to generate hydrothermal activity and maintain a liquid subsurface ocean.

The Clipper will perform 45 flybys of Europa, diving from 2,700km to just 25km above the surface, and is equipped with nine science instruments to collect data along the way. The spacecraft will search for any plumes bursting through Europa's frozen crust, as these could contain water vapour and might point to a subsurface ocean. It will then analyse the material, searching for potential water particles in its atmosphere and collecting data. Other data should also give scientists a detailed picture of Europa's magnetic field and gravitational pull, the thickness of its crust and the depth of its ocean.

If life does exist beyond our home planet, Europa is currently one of our best chances of finding it. On Earth we tend to see an abundance of life wherever water exists, so the prospect of a salty ocean hidden on an icy moon is too tempting to pass up. Subsequent missions may even be able to put a lander on Europa and explore the salty liquid below its surface. And, if scientists can find what they're looking for, it may be enough to at least partly answer the question as to whether we are alone in the Universe.

THE HUNT FOR H_2O

Recent discoveries show that water may be found in many regions of the Solar System, hinting at potentially suitable conditions for life, past and present

MARCH 2015: Astronomers announce that observations with the Hubble Space Telescope show evidence of a salty, subsurface ocean on Jupiter's largest moon Ganymede.

OCTOBER 2015: The Cassini spacecraft dives through erupting plumes on Saturn's moon Enceladus, revealing salty liquid water and organic molecules below its icy crust.

JANUARY 2016: New Horizons data reveals more water ice on dwarf planet Pluto than previously thought.

OCTOBER 2017: Data from the Dawn mission shows evidence that there was once a global ocean on dwarf planet Ceres, the largest body in the Asteroid Belt.

JULY 2018: The European Mars Express orbiter finds evidence that a lake of liquid water could exist below the surface of the Red Planet today.

AUGUST 2018: NASA detects chemical signatures of water above Jupiter's deepest clouds.

Studies over the past decade have also suggested the presence of subsurface oceans in 'Trans-Neptunian Objects' on the edge of the Solar System, billions of kilometres from the Sun.

THE NEW GOLD RUSH

Giant spaceships hopping between asteroids, ripping them apart and shipping their resources across the Solar System. While space mining is still a decade or so off, next year the industry is ramping up their efforts

WORDS: **ELIZABETH PEARSON**

The asteroid belt is brimming with metals – everything from iron and nickel, to gold and platinum. It's estimated there is at least $700 billion billion worth of mineral wealth in the belt, and companies are being set up all around the world to plunder these resources in a gold rush for the 21st century.

"It's the next boom industry. Once you set up the infrastructure then the possibilities are almost infinite. There's an astronomical amount of money to be made by those bold enough to rise to the challenge of the asteroid rush," says Mitch Hunter-Scullion, who founded the UK-based Asteroid Mining Company just after leaving university. The company plans to launch its first prospecting satellite in 2020 and start mining operations in space by 2030.

But there is more to space mining than a gold rush for the sci-fi age. Taking mining off Earth could help relieve humanity's destruction of our planet's environment. Society's hunger for technology is fed by the rare earth metals needed to make the electronics inside our latest gadgets. Mining these metals causes a huge amount of damage to both the surrounding ecosystem and the miners.

"On Earth rare earth metals are mined under highly toxic and unethical conditions," says Hunter-Scullion. "[With space mining] you can't exploit a robot. And it moves all of the polluting industries into deep space, where there is no delicate biosphere to damage. I imagine a future where the Earth will be the protected garden of the Solar System, and all the heavily polluting industries will move off into orbital factories built around captured asteroids or lunar industrial complexes."

New mines in space could also provide a new source of rare elements to help create the tools we need to alleviate the current environmental crisis. Solar panels, electric cars and energy-saving light bulbs all rely on elements that are increasingly rare on Earth, such as platinum.

"As well as being worth $26,000 per kilo, platinum is one of the main ingredients of catalytic converters that allow hydrogen cars to work, and normal cars to run cleaner," says Hunter-Scullion. "But it is a highly limited resource, so if we can bring more onto the planet then we can run more environmentally friendly cars and combat one of the major sources of climate change."

Space mining will play a critical role in allowing humanity to venture away from the planet on a regular basis. Building giant spacecraft on the ground and then

GETTY X2

MINING TARGETS

- **THE MOON**
  Many refining and manufacturing techniques in metal processing rely on gravity. The Moon's gravity is only a sixth of ours but it's enough to create a stable operations base close to Earth.
  Resources: *Helium-3, gold, platinum group metals, rare earth metals, water*

- **NEAR-EARTH ASTEROIDS**
  Some asteroids naturally pass close to Earth. These could easily be corralled into a convenient orbit where their water can be extracted, but other useful elements might be limited.
  Resources: *water, iron, nickel*

- **THE ASTEROID BELT**
  The asteroids of the main belt contain almost any metal or element we could ever need. But with asteroids up to 750 million km from Earth, they are difficult to reach.
  Resources: *almost everything*

- **JUPITER**
  Not all mining is rock and ore. It could also be possible to 'mine' the atmospheres of the gas giants for rare gases such as Helium-3, for use in fusion technology. However, Jupiter is over a billion km away.
  Resources: *Helium-3*

launching them is hugely inefficient, especially when there is an almost unlimited source of iron and titanium already in space. You can even find the most vital resource to human spaceflight – water.

"It's uniquely useful in space because you can take the water molecule and split that into hydrogen and oxygen, which is rocket fuel," says Chris Lewicki CEO of Planetary Resources. In 2020, the company will send out spacecraft to survey near-Earth asteroids for water. Eventually, Planetary Resources aim to bake the water out of these rocks, turning them into Space Age petrol stations.

"We have reusable space vehicles that are very good at getting to low-Earth orbit," Lewicki says. "We can now start to make extremely specialised vehicles that go from the edge of space to somewhere further out."

This autumn, the Colorado School of Mining will run the world's first space resources university course, the graduates of which will join the likes of Hunter-Scullion and Lewicki and head out into space to make their fortune.

The new gold rush has begun.

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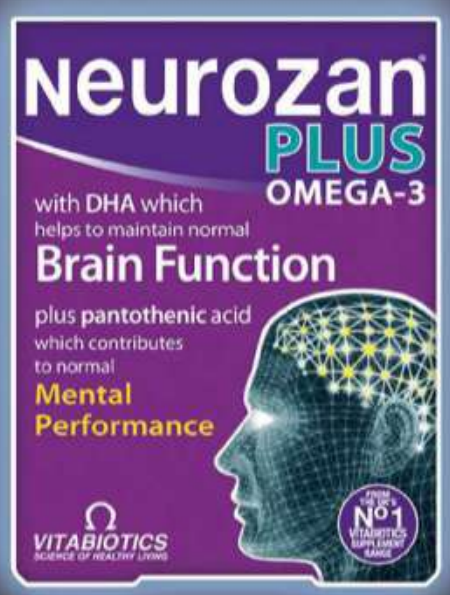

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VITABIOTICS
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2018-08-22 ADNEUCONP E

"I predict (with caveats) that 2019 will see people becoming more comfortable with robots in the home. They will eschew privacy concerns for shiny new features."

DR ALEKS KROTOSKI
social psychologist, journalist and broadcaster, presenting BBC Radio 4's Digital Human

"Carbon-based materials for next-gen electronic devices will be big news in 2019. These devices can be biocompatible, low-cost, lightweight, ultra-thin and flexible."

DR JESS WADE
physicist at Imperial College London and winner of the Daphne Jackson Prize from the Institute of Physics

"2019 will see the first significant monetary penalty issued by the UK's Information Commissioner's Office (ICO), for an infringement against the recently introduced General Data Protection Regulation (GDPR)."

SIMON BABES
MD at Movement Strategies, which specialises in crowd flow planning

TECH IN 2019

GETTY

THE CHANGING FACE OF OUR CITIES

Big changes are needed for our cities to become healthy, sustainable places to live. Some are already taking place and more are on the way, but not all of them will be immediately obvious

WORDS: **ROB BANINO**

On Monday 8 October 2018, the Intergovernmental Panel on Climate Change (IPCC) issued a report that said not enough was being done to avoid the worst consequences of global warming. It contained a stark yet simple warning: the most severe effects of climate change can be reduced if we limit the rise in global temperatures to 1.5°C above pre-industrial levels. But doing so will require rapid and far-reaching changes.

It's no surprise that one of those changes required, perhaps the biggest, is the shift away from fossil fuels. We need to significantly increase the use of alternative fuels in order reduce our carbon footprint; climate scientists have been saying as much for years. And the simplest way of doing this would be for us to 'go electric', especially in our cities where the concentration of people and energy demand are highest.

"Electrification is one route," says Stephen Hall of the University of Leeds's Centre for Climate Change, Economics and Policy. "The reason for that is the electricity grid will accept any form of electricity so long as it's of the right power quality… [whether it's] from intermittent renewables [solar and wind] or prime renewables like biomass.

"I think the electrification of cities is probably one way to provision us with the sort of energy services we're used to in a low-carbon fashion."

The electrification of our cities is already taking place, most notably on the roads. Electric vehicles are becoming an increasingly common sight as they make the most sense in places where the majority of journeys are short. And, although they are expensive to buy compared to equivalent internal combustion engine vehicles, we'll be seeing more of them in the years to come. Why? Partly because they're necessary; partly because more manufacturers are shifting their focus to electric vehicles exclusively; but also because there are financial benefits to owning one.

The switch to electric vehicles isn't happening fast enough

In the UK, electric vehicles that retail for less than £40k are exempt from road tax; there's no fuel duty to pay on the electricity they use; and the VAT on recharging with electricity at home is five per cent, as opposed to the 20 per cent you'd pay refuelling at a pump.

Despite all this, the switch to electric vehicles isn't happening fast enough. And, in the wake

GETTY

of the IPCC's report, MPs called for the ban on the sale of new petrol and diesel vehicles to be pulled back from 2040 to 2032. Whether the date for that ban will change was undecided at the time of going to press. Nevertheless, Hall expects further, more visible changes to the road network in the years ahead to encourage not only the switch to electric vehicles but also a reduction in vehicle use overall.

"It'll be really obvious stuff like more two-plus [passenger] lanes, and more bus lanes (and you can drive in some bus lanes if you've got an electric car). More low-emissions zones are coming as well, but if you're in an electric car you can drive through them for free."

CHARGES AND RECHARGING

Currently there are low emissions zones in London, Brighton, Norwich, Nottingham and Oxford, but it's only in London that the cost for entering the zone is applied to vehicles other than buses. That may change soon, however, possibly with Bath leading the way – its local council is proposing a scheme in which motorists pay a £9 'clean air charge' to drive into the city centre from 2020.

Financial incentives and new road layouts aren't all that's required to hasten the switch to electric vehicles, though. Changes to our infrastructure will be needed in order to keep them running, because charging electric vehicles takes time – it's getting faster, but charging a battery still takes considerably longer than filling a fuel tank.

Charging at home overnight is therefore the most convenient option and some car manufacturers will install a charging unit for free when you buy one of their vehicles. But that relies on you having off-street parking and nearly one third of British car owners, many of whom live in cities, don't have that luxury. Catering to that third will result in another change: a growing network of public charging points.

The increasing proliferation of public charging points may be more subtle than you might expect, however, as many of them will be integrated into existing lamp posts to keep 'pavement furniture' to a minimum.

Helping that network grow are government grants, available at the request of your local authority, to have on-street charging points installed in residential areas. There are further subsidies available to employers that wish to have charging points installed in the

ABOVE: **On-street charging will become an increasingly common sight on Britain's roads**

HOME IMPROVEMENT

A new approach helps you keep warm and save energy

Electric vehicles put a relatively small demand on our power supply. The biggest comes from heating our homes. There are low-carbon heating technologies we could implement (air-source heat pumps and combined heat and power networks, for example) that wouldn't require massive changes to the gas pipe infrastructure. But although heat pumps are greener and more efficient than existing methods, they don't deliver as much heat, so for them to be a practical alternative we'd need better insulated homes.

One affordable way of getting them was trialled in Nottingham in 2018. Based on the 'Energiesprong' model developed in the Netherlands, it involves installing prefabricated insulated facades and roofs with integrated solar panels to houses. The makeover results in a 'net zero energy' house that, according to Energiesprong (energiesprong.eu) "generates as much energy as is needed to heat it, provide hot water and power its appliances".

The scheme is geared towards the social housing sector and achieves its funding via the savings the refurbishments generate. So if a tenant is paying £2,000 for their annual energy bill before the installation, they continue to pay that amount afterwards but instead of that money going to the energy supplier, it goes towards paying off the cost of the refurbishment. In the meantime, the tenant's home is being heated and powered more efficiently and with less environmental impact.

car parks attached to their premises.

Facilitating these changes in our cities will require changes in other areas too, most notably on the east coast where the massive Hornsea One and Two wind farms are currently under construction. They are expected to come online between 2020 and 2022, by which time construction of a nearby Hornsea Three wind farm is hoped to be underway.

"Electric vehicles are a great place to put that wind energy during the night when nobody else is using it," explains Hall. "Electric vehicles put a demand on the system during the night when otherwise those new renewable power producers would have to accept a lower price because demand is lower on the system. So electric vehicles and offshore wind in particular are best friends."

THE DRIVE FOR CLEANER AIR

'Going electric' doesn't solve all our problems, however. There's growing concern over the health implications of air pollution, which is believed to be linked to approximately 40,000 premature deaths annually in the UK. And while switching to electric vehicles takes engine emissions out of the equation, it might not be so helpful when it comes to particulate matter, as Rachel White, the senior policy advisor for Sustrans points out.

"The issue with this is that in London (where there's good data), 45 per cent of particulate matter (of which the WHO says there are no safe levels) actually comes from tyre and brake wear. And that isn't really addressed at all by electric vehicles… [T]he regenerative braking of electric vehicles may see a reduction in brake wear but the fact that electric vehicles are heavier, because they have heavy batteries, means you're more likely to see an increase in particulate matter from tyre wear."

And, as White says, it's not just air pollution that needs addressing; our health in general is in decline due to inactivity. "[In September,] *The Lancet* published a report that basically found that 1.4 billion adults across the world – about a quarter of the world's adults – are doing far too little exercise and that this is the only area in which we've got a health problem that's getting worse. Problems in other areas, such as diseases, are generally improving. And they found that the easiest way of addressing this problem was to incorporate infrastructure for cycling and walking."

Which is why Sustrans is pushing for a slightly different approach to changing our cities.

"What Sustrans is saying is that we don't just need cleaner vehicles, we need fewer vehicles… We believe electric vehicles have a role to play because we're not going to get rid of cars entirely – there are certain journeys that need to be made by car… But we're seeing the air pollution crisis as an opportunity for town planners and cities to rethink the way that towns and city centres are organised and how people can move around them differently."

In short, change is needed in our cities and, to a certain degree, it's already occurring. But it's not actually the cities themselves that need to change, but the way we travel around them.

GOING DUTCH

More provisions for cyclists leads to more people cycling

The number of cars on our roads needs to be reduced and one way of doing that is to make cycling a viable alternative to driving. The 'Mini Holland' programme in London is an attempt to do just that by mimicking the bicycle-friendly infrastructure in the Netherlands, where approximately 27 per cent of all journeys are made by bike.

In 2013, three boroughs – Enfield, Kingston and Waltham Forest – were selected to share a £30 million grant to make changes to their roads, pavements and cycle paths to increase the number of journeys made by bike or on foot.

It didn't take long for the changes to have an effect. According to research, the number of residents making journeys by bike grew from 12 to 17 per cent between 2015 and 2016. A more recent study published in *Transportation Research* in 2018 found that the average time spent on active travel (walking or cycling) per week in the three Mini Holland zones had increased by 41 minutes since the changes.

The Mini Holland programme is due to be completed by 2021. If the improvements seen in the three test boroughs are maintained, or increase, it's likely to be rolled out to more areas across London and the rest of the UK.

BBC RADIO 4

Listen to an episode of *Costing the Earth* discussing whether the time is finally right to buy an electric car
bbc.in/2yorli4

GETTY, ALAMY, ENERGIESPRONG

BACK-SEAT DRIVER 2.0

Car manufacturers are integrating virtual assistants into their vehicles to help you focus on driving

WORDS: **ROB BANINO**

It's illegal to use a handheld phone or device while driving in the UK, as the distraction makes life a lot more dangerous for you, your passengers and any other road users or pedestrians around.

But drivers still want to make calls, check schedules, adjust sat-navs or switch playlists without taking their hands off the wheel or eyes off the road. So in recent years car manufacturers have been building voice-command technology into their vehicles.

The technology is becoming ever more sophisticated and the latest versions – such as those that came on the market in 2018 from Audi and Mercedes, and the one BMW is introducing in its 2019 vehicles – use artificial intelligence to better recognise and respond to conversational speech rather than a few predetermined phrases.

BMW is touting its 'Intelligent Personal Assistant' system as an in-car AI companion, similar to the Siri and Alexa systems that have found their way into our phones and homes. So asking: "Hey BMW, how does the high-beam assist work?" prompts the BMW assistant to explain how the car automatically switches between full-beam and dipped lights on unlit roads when it senses other vehicles approaching. Similarly, saying: "Hey BMW, I'm tired", activates a range of lighting, music and temperature functions to help keep you alert.

Give the BMW assistant access to your calendar and contacts and it's said to be able to find a suitable parking spot at your next destination. Perhaps most importantly, though, you can also program it to respond to a name other than 'BMW'.

The latest versions use AI to better recognise and respond to conversational speech

Voice-command tech lets you talk to BMW's Intelligent Personal Assistant more conversationally (in various languages)

BMW

THE DIGITAL SILK ROAD

China's expansion of its digital communications infrastructure will have global implications in the years to come

WORDS: **RUSSELL DEEKS**

China has the second largest economy in the world, valued by the International Monetary Fund in 2018 at $14 trillion – not far behind the US at $20.4 trillion. And now, with a view to narrowing that gap, the country is embarking on a huge programme of digital infrastructure expansion that's been named the Digital Silk Road – a reference not to dark web drug supermarkets, but to ancient trade routes linking east and west that date back to Biblical times.

In 2013, the Chinese government announced the 'belt and road initiative' (BRI), a major 21st-century overhaul of the various roads, railways and ports that connect China with central Asia and Europe. Somewhat counterintuitively, the 'belt' in the name refers to overland routes, the 'road' to sea routes but, in 2015, China announced plans for a third component – the Digital Silk Road.

This is a wide-ranging project, but it will have two key aspects. Firstly, China will be providing upgraded internet connections in the form of new undersea cables linking east and west, as well as the roll-out of broadband in countries en route where such infrastructure is under-developed or non-existent, boosting their economies. And, secondly, China's BeiDou satellite navigation network is to be massively expanded so that it becomes a true, global rival to the US-owned GPS system.

BIG BUCKS

The numbers involved are staggering. Chinese firm ZTE, for instance, was recently given a $23 million loan by the World Bank to develop a fibre-optic network in Afghanistan, while another $32 million has been earmarked for dealing with environmental challenges posed by the development works – just two of dozens, if not hundreds, of different projects falling under the Digital Silk Road banner. And that's not to mention the estimated $25 billion cost of expanding the BeiDou network from a mere 17 satellites covering the Far East, to 35 covering the entire world. The new satellites have already been launched – one of the biggest projects for 2019 will be commissioning them and bringing them online.

In total, the Digital Silk Road alone (in other words, not counting the rest of the BRI project) is estimated to involve nearly $200 billion's worth of investment. This will undoubtedly give a huge boost to the Chinese economy, as well as to countries such as India, Pakistan and Nepal, but some observers in the West have expressed their unease. They argue that China's extensive surveillance and censorship, makes it unfit to 'own' such a large chunk of the world's communications infrastructure – and point out that satellites that can guide drivers, can also guide missiles.

DRONE ALERT

Next year is all about testing the technology and writing the rules that will set up our skies for fleets of unmanned aircraft

WORDS: **ROB BANINO**

The world's first drone-delivered pizzas landed in November 2016, when Domino's flew a pair of chicken-topped ones to a couple living 25km north of Auckland, New Zealand. Since then many businesses, including online retail giant Amazon, have investigated using drones to carry products to customers.

It'll probably be at least a few more years before fleets of delivery drones are buzzing over our heads, but we're likely to see steps towards that being taken in the year to come. The most obvious one will be the appearance of the CE mark to show that any drone being sold to the public meets the new Europe-wide safety certification soon to be introduced.

"At the moment there aren't any pan-European regulations for drones," says Jonathan Nicholson of the Civil Aviation Authority.

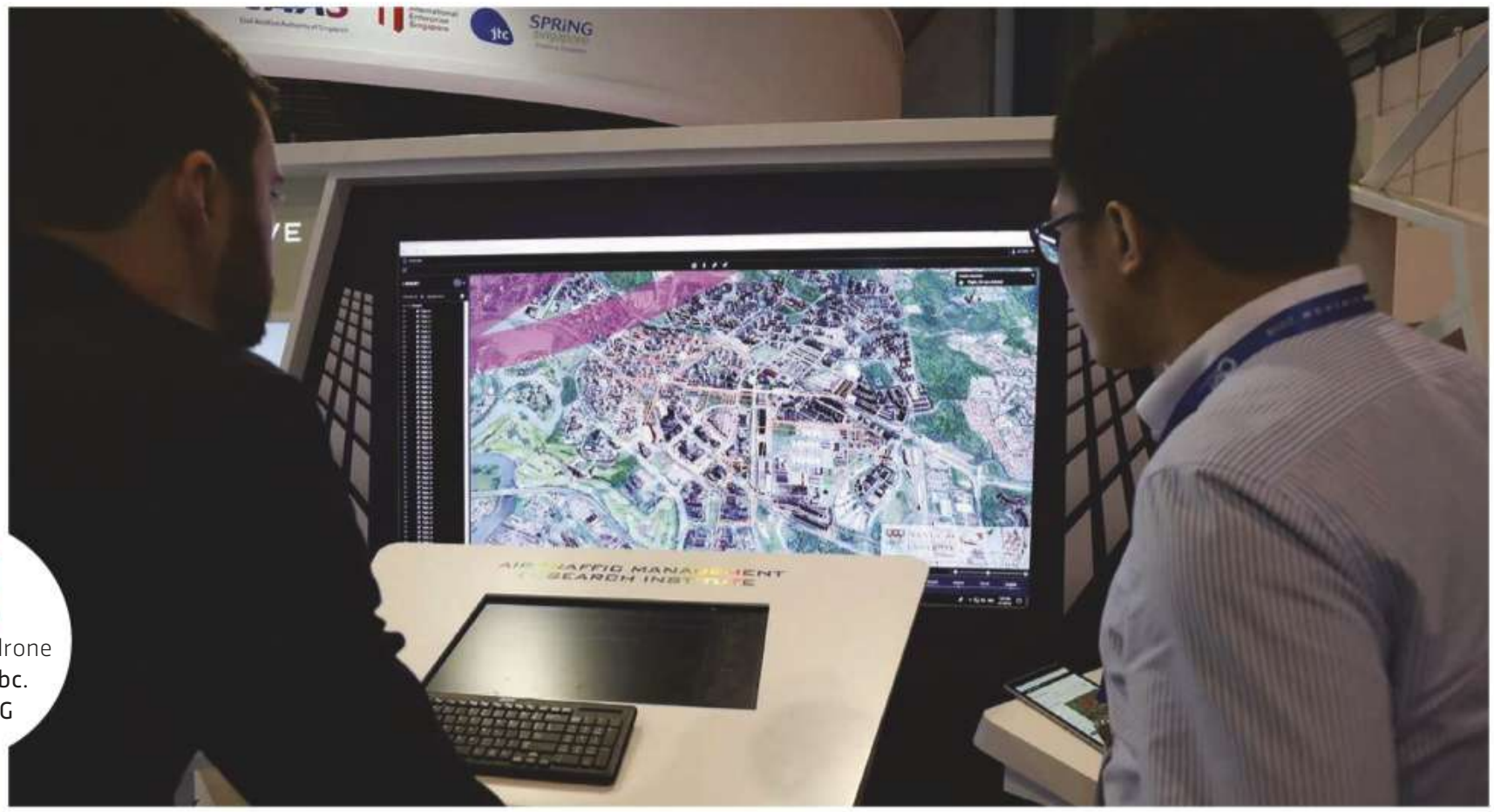
But there soon will be: the European Aviation Safety Agency (EASA) has written them and the final versions will be announced shortly.

"As well as rules for how and when drones can fly, which will be very similar to what we already have in the UK [see dronesafe.uk], EASA will also be introducing safety requirements for manufacturers. So there will be a CE mark for drones and to receive it any drone over 250g must comply with those requirements, which will include things like geofencing."

Geofencing is GPS-based technology that creates a virtual boundary around specific locations, such as airports and prisons, to prevent drones from entering their airspace. But as Nicholson points out, part of the issue at the moment is that not every drone is fitted with geofencing, and it can be easily overridden in those drones that do.

But there's a bigger problem than keeping drones out of airspace they shouldn't be in – air traffic control. Whether they're delivering pizzas, ferrying organs between hospitals or monitoring road accidents, piloted or autonomous drones will be operating in uncontrolled airspace, where it's currently impossible for other aircraft – which could be anything from helicopters, to hot air balloons, or even military fast jets – to be made aware of their presence and safely avoid them.

"There's no overall air traffic



BBC NEWS

Click looks at drone deliveries **bbc.in/2CRPplG**

ABOVE: Singapore Airshow attendees check out an Unmanned Aerial System Traffic Management (UTM)

LEFT: An M2 delivery drone carries lab samples between hospitals during a trial flight in Bern, Switzerland

GETTY X2

control system for uncontrolled airspace," Nicholson explains. "In years to come, we will undoubtedly have a unified air traffic system where every aircraft [including drones] automatically transmits its location and flightpath data to everything else and all the aircraft in uncontrolled airspace avoid each other automatically. But we don't have that yet, nobody does. There's lots of work being done on it but, until we get to a position where a drone can be trusted to sense and avoid everything on its own, we have the 'you can't operate beyond visual line of sight' rule, which stays in place."

NASA is just one of the organisations developing an air traffic control system for drones (which it refers to as "unmanned aerial system traffic management", or UTM for short) and has spent the last few years putting it through its paces. The third phase of testing, which involved keeping drones safely spaced out while detecting and avoiding other drones over moderately populated areas, was completed this spring. The fourth, and perhaps, final phase is scheduled to begin in 2019 and will see if NASA's UTM system can integrate drones into more populated urban areas in order to test "package delivery, infrastructure inspection, aerial photography, news gathering, public safety and first responder operations".

Closer to home, UK firm Aviation Angel has partnered with NATS (National Air Traffic Services) to develop UTM systems that can be integrated with conventional air traffic control technology and procedures.

As work continues on the technical aspects of identifying unmanned aircraft, their flightpaths and the software they'll require to sense and avoid each other, 2019 will see further testing of the systems currently in development. But the coming year is also likely to see changes to flight regulations in order to make commercial drone use possible over urban areas.

Currently, the drone code prohibits them from flying above 120m and beyond the operator's line of sight. Crucially, they also can't be flown within 50m of people and property, or within 150m of crowds and built-up areas. It's likely some, perhaps all, of those rules will have to change if drone use, particularly for deliveries, is to become viable in cities.

In short, 2019 could turn out to be an important year for the drone industry. Trials of various UTM systems will be taking place in the US, Switzerland, Spain and Japan. Recommendations concerning the future use of drones will be made to governments and aviation authorities based on the outcomes. If the UTM systems are proven to be effective, there's a chance we could see more than pizzas being delivered by drone in 2020.

KEEPING AN EYE ON VR

Eye-tracking technology is on its way to virtual reality headsets

WORDS: **ROB BANINO**

Expect to see eye-tracking tech in virtual reality headsets in the near future. The technology will help us to see VR worlds in the same way that we see the real world.

Our eyes are sophisticated organs, but they don't show our entire field of view in focus. Instead, due to the higher concentration of photoreceptor cells in the middle of our retinas (an area known as the fovea) the centre of our view is sharp while everything in our peripheral vision is less detailed.

Eye-tracking technology mimics this by monitoring exactly what you're looking at within an image and only rendering that small part sharply. It's a process called 'foveal rendering' and it's needed so VR systems can refresh higher resolution images sufficiently quickly without requiring faster computer processors – making for better, more affordable machines.

GETTY

BBC NEWS

Watch a clip of how eye-tracking tech works **bbc.in/2wGvQbz**

Eye-tracking technology monitors exactly what you're looking at in an image and only renders that part sharply

JOBLESS BY 2020?

Will artificial intelligence spell armageddon for the jobs market – or actually boost it?

WORDS: **RUSSELL DEEKS**

In August, retailer Marks & Spencer announced it was introducing AI chatbots to deal with customer calls to its 640 UK stores and 13 call centres. The system M&S has adopted uses a combination of Twilio voice recognition software and Dialogflow, an AI developed by Google. It won't actually deal with a customer's enquiry; rather, it'll simply redirect them to the appropriate store or department (much as many existing, non-AI automated switchboards already do). But the news was nonetheless greeted with consternation by those who predict a 'jobs apocalypse' brought on by the widespread implementation of AI.

While artificial intelligence doubtless brings many advantages – ask any research scientist about the benefits of being able to analyse huge datasets thousands of times quicker than a human could – many people are worried that AI (or more accurately, automation using a combination of AI and robotics) could spell the end of their jobs. And depending on what job it is they're doing, they may well have a point.

A LESSON FROM THE PAST

If we look at the history of technology, there are many examples of machines replacing human beings – the onset of the industrial revolution saw weaving as a cottage industry go into rapid decline. More recently, the introduction of robotics has seen millions of production line jobs in factories simply disappear.

A study estimated that over the next two decades, AI could cause seven million redundancies, but 7.2 million new jobs would be created

Now, thanks to AI, anyone whose work largely involves following a routine set of procedures and making a routine set of decisions – from call centre workers and CCTV operators, to property lawyers and bank clerks, to court reporters and radiologists – may soon find that a computer can do it better, more quickly and cheaply than they can. Former chess world champion Garry Kasparov – who was himself famously bested by a computer way back in 1997 – has described this as "the cost of progress", telling the Tableau Conference Europe that: "We used to lose manufacturing jobs to machines – the only difference now is the people who are at risk have college degrees and Twitter accounts."

That's the bad news – but there are reasons for optimism, too. Firstly, many experts suggest that artificial intelligence will 'shred' jobs rather than destroy them and, secondly, the number of jobs that new technologies create also has to be taken into account when considering their impact on employment.

What does 'shredding' jobs mean? Take

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> **“We used to lose jobs to machines. Now people at risk have college degrees”**
>
> GARRY KASPAROV
> *Former chess world champion*

the case of a radiologist: a computer may be able to examine CAT scans for anomalies that may indicate cancer, but it’s unlikely any hospital would allow a treatment programme to be instigated without human oversight somewhere along the way. Very few jobs in fact, are *entirely* a matter of routine – most require some degree of human input. So it may well be that AI replaces *tasks*, rather than jobs – freeing up workers from mundane, repetitive aspects of their job so they can focus on ‘human’ elements such as customer relations.

CREATING JOBS

More importantly, there’s the issue of the jobs that AI will create. Again, we can look to history here. Many of those former weavers took jobs as machine operators in mills; once the internal combustion engine arrived, many an ex-coachmaker found themselves working in a car plant. AI is set to become a huge industry in its own right, employing countless programmers, computer scientists and engineers – and that’s not to mention new jobs we haven’t even thought of yet.

In fact, a recent large-scale study carried out by accountancy giant Price Waterhouse Coopers concluded that over the next 20 years, some seven million jobs would be lost to AI, but that around 7.2 million new jobs would be created as a result of it.

“In some sectors, particularly where jobs involve low-level repetitive tasks, the net effect of AI may be negative, with the potential for some jobs to become extinct,” says Dr George Panoutsos, Reader in Computational Intelligence at the University of Sheffield. “But in the broader manufacturing sector, I would expect to see significant growth in terms of demand for new skills, new processes, new legislation and standards, which all would generate jobs.

“In the short term,” he continues, “jobs that evolve around all aspects of creating, maintaining and using AI systems (from engineering and computing, to legislation and ethics) would see some growth. It’s challenging to predict what type of new jobs would emerge, however, one aspect could be the need to have expert users of AI systems, acting as the ‘interface’ between AI and the general population.”

Similarly, while Bank of England chief economist Andy Haldane has spoken ominously of the “technological unemployment” that AI might cause, he’s also spoken of the “skills revolution” that could counter those effects.

Experts all agree that artificial intelligence *is* going to impact upon the jobs market. Quite what form that impact will take remains to be seen, but there’s probably no reason to worry about global mass unemployment just yet.

Oh, and those M&S workers affected by the implementation of AI? They’ve all been found jobs elsewhere in the business.

BBC RADIO 4

Listen to a series of PM – *Will a robot take your job?*
bbc.in/2qkv4y6

HOW TO GET A JOB IN AI

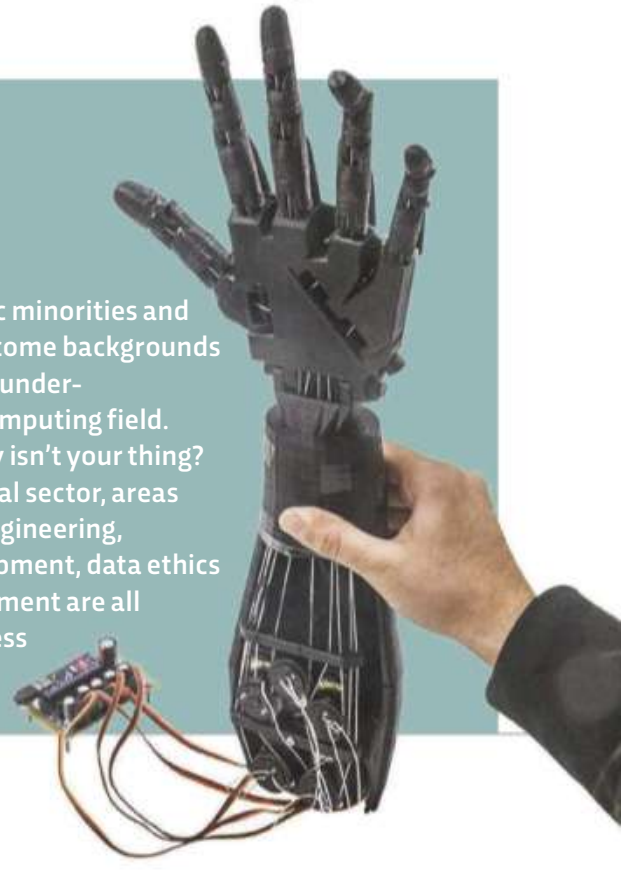
If AI’s going to create lots of new jobs, what do you need to do to get one?

According to LinkedIn’s 2017 Emerging Jobs Report, two of the fastest-growing jobs at the moment are ‘machine learning engineer’ and ‘data scientist’. That’s because, while AI might create all sorts of jobs in the future, right now most of the jobs involve creating the AI.

Many major universities including those of Leeds, Sheffield, Birmingham, Nottingham and Kent now offer specialist BSc courses in artificial intelligence (or AI and robotics), while many more run post-grad courses to MSc level. So for younger people, that would be the obvious place to start.

If returning to full-time education isn’t an option, many online learning providers also run AI courses that can usually be studied at your own pace, including Udacity, Nvidia and Coursera. And there’s one online provider – AI4ALL – catering specifically for groups, such as ethnic minorities and children from low-income backgrounds that are traditionally under-represented in the computing field.

And if coding really isn’t your thing? Then in the managerial sector, areas such as process re-engineering, business case development, data ethics and IP rights management are all going to be big business as AI booms.



TALKING POINT

JIM AL-KHALILI

The physicist and BBC presenter reveals why we shouldn't be afraid of artificial intelligence

INTERVIEW: **ALEXANDER MCNAMARA**

HOW IMPORTANT IS ARTIFICIAL INTELLIGENCE GOING TO BE IN THE NEXT FEW YEARS?
Technology involving AI is rapidly evolving. We've not got there yet, but we're moving very fast towards it.

BUT WE ALREADY HAVE THINGS LIKE ALEXA...
When people talk about AI, they tend to mean something general. For example, SIRI and Alexa help answer questions, they sound as though they're intelligent and figuring stuff out for you. Likewise, a complex computer programme can do things much more quickly than the human brain. For example, it can beat a grand master at chess, giving it the appearance of intelligence. But what it's really doing is just running an algorithm, number crunching.

SO WHAT IS TRUE AI?
What we mean by true intelligence, nowadays, is if the machine uses something called machine-learning, whereby it's not simply given a set of instructions by a programmer and follows them blindly, but learns as it goes, building its own code. That's what modern AI machines are doing now. They use something called neural networks which are meant to mimic, in a sense, the way our brain works. A neural network is an abstract mathematical version of the human brain, and it is starting to show real intelligence by anyone's definition.

HOW CLOSE ARE WE TO THIS?
Artificial intelligence machines are a long way behind what human brains can do. An AI can look at a picture of a dog and understand from the pixels what it represents, but it doesn't know what a dog is. It doesn't understand the concept of 'dog'. And so, while it can do certain things faster and more efficiently, and even sometimes in more clever ways than humans, that's still not intelligent in the way that we would talk about it. I think the problem is, we're often too infected by Hollywood movies. And so, we think of AIs, or being intelligent, as somehow being conscious – being self-aware. That may come in the future, but we're many decades away from that.

IS ARTIFICIAL INTELLIGENCE REALLY THE RIGHT SORT OF PHRASE THEN?
Probably not, in hindsight. If we had to redefine it, we'd call it something else. Machine-learning, deep-learning or artificial neural-networks are maybe more accurate. They're just not quite as catchy as artificial intelligence, AI.

WHAT IS TRUE AI CAPABLE OF NOW?
When an AI was tasked with the Chinese game of Go (which people regard as a better indicator of innovative ways of thinking than, say, Chess), it made a move that seemed silly at the time, but it was only much later on in the game that we appreciated what a genius move it was, because it became important as the game developed. So, it had discovered a solution to a problem that the people

Software, like SIRI and Alexa, do not use the neural networks of true AI

who built the machine didn't understand and weren't expecting. That's real innovation going on inside these deep-learning machines.

THAT SOUNDS INCREDIBLE, BUT ALSO A BIT SCARY...
Yes. That is what a lot of people are concerned about. What if they start getting smarter and smarter, ever more quickly? What if they reach what we would refer to as the singularity – they develop 'artificial general intelligence', become self-aware and decide that they don't need humans? This is the Skynet scenario from the Terminator movies. But people who work in AI are much more optimistic that we can maintain control and build in sufficient safeguards. Even though AIs may end up being more intelligent than us, they would still be in our control. I think we should be more nervous about the fact that AI is still very dumb, and potentially dumb but powerful people will control it, for reasons that are not so good. Technology itself is not good or evil. It is just the application of scientific ideas. It's how we humans use technology.

DURING THE INDUSTRIAL REVOLUTION, LUDDITES SMASHED UP MACHINES BECAUSE THEY SAW THEM AS A THREAT. 100 YEARS DOWN THE LINE, WILL WE REALISE THE BENEFITS OF THIS ARTIFICIAL INTELLIGENCE REVOLUTION?
I'm convinced that will be the case. Of course, at the time, when technologies start to replace human labour, there's always a push-back, and understandably so. People will lose their jobs, but AI will also create new ones that haven't been invented yet. Steam engines replaced humans as they could do the job more efficiently and cheaply. Likewise with robotic arms on factory production lines. So, this is just another in a long line of technologies replacing humans in doing certain jobs. The difference with the AI revolution is that we're still not sure how much of an impact it will have. We've only had the Internet and the World Wide Web for a quarter of a century. AI will change our lives equally if not more than the Internet, and it'll do it far more quickly than the next 25 years. It's coming so fast, and it's going to change so many aspects of our lives. It's very exciting, but we need to make sure we know what's coming over the horizon. We shouldn't be afraid of it. We should just be prepared. F

BBC FOUR Watch clips of *The Joy of AI* bbc.in/2x3a9TO

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CAN MATHS DEFEAT TERRORISM?

Acts of terrorism always come as a shocking surprise. But mathematicians are spotting patterns in terrorist atrocities and behaviour that may help to counter the threat

WORDS: **ANDY RIDGWAY**

Counter terrorism officers march near the scene of the London Bridge attack on 4 June 2017

GETTY

Are there patterns in terrorist attacks that could help us predict or even prevent them? It's a question that first occurred to Prof Neil Johnson, a physicist at the University of Miami while he was visiting Colombia in the 1990s.

Since the mid-1960s, the country has been in the grip of a conflict between the government and various insurgent groups. "I'd turn on the news and see that three people were killed today, then no one the next, then five, then two, then six," says Johnson. "It's a complicated set of numbers and I thought, let's look at them." His efforts to find a signal in that noisy data proved fruitful.

Later, when he and economist Prof Mike Spagat at Royal Holloway, University of London, analysed a database of 20,000 attacks in Columbia and plotted them against the number of people killed in each one, they ended up with a distinctly shaped graph. It started high near the Y axis, but dropped steeply before levelling off and running almost parallel with the X axis.

The graph's high peak reflected the small number of attacks that had high death tolls, while its long tail was indicative of the large number of attacks with smaller numbers of casualties. Interestingly when they did the same with data on attacks that followed the 2003 invasion of Iraq, it showed exactly the same pattern. What they'd discovered was a mathematical relationship called a 'power law', something that computer scientist Asst Prof Aaron Clauset at the University of Colorado at Boulder stumbled upon at a similar time.

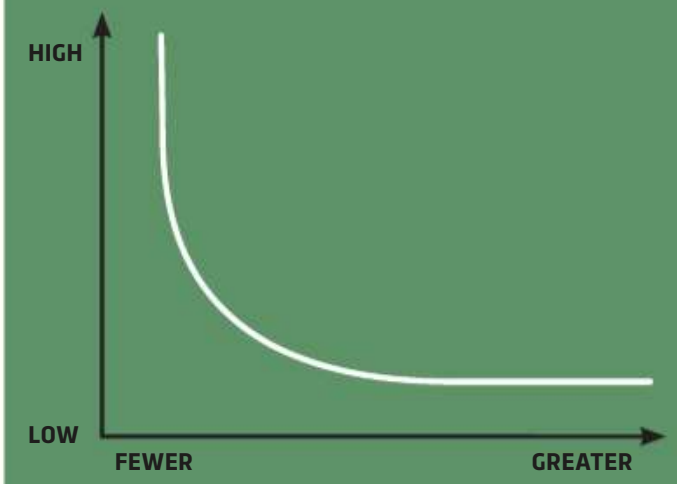
The discovery of the power law relationship between the number of attacks and the number of people killed allows forecasts to be made. "It allows us to extrapolate in a mathematically principled manner, to make statements about events that are incredibly rare," explains Clauset.

This kind of extrapolation led to Clauset's forecast that the chance of another terrorist attack on the scale of 9/11, which killed 2,996 people, is 30 per cent over the next 10 years.

The chance of another terrorist attack on the scale of 9/11, which killed 2,996 people, is 30 per cent over the next 10 years

The maths can build expectations about the frequency of large-scale terror events, says Clauset. "But it doesn't allow us to predict when, why or how the next event will happen."

Some researchers, though, are using maths to try and predict who will be behind the next attack. When they compared the number of insurgent groups in places like Iraq and Colombia with the sizes of those groups,

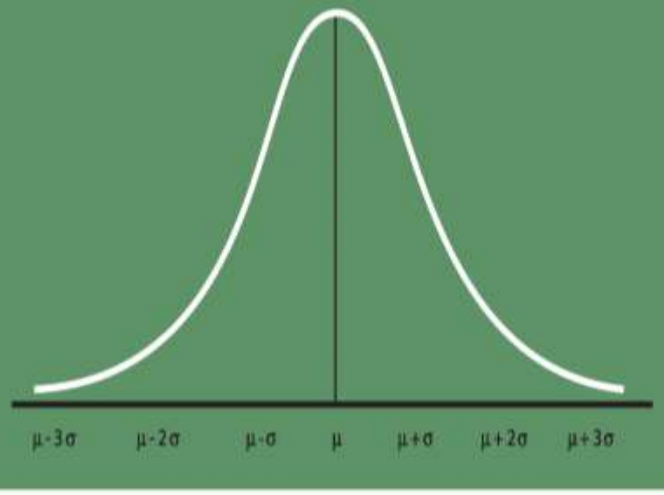


WHAT IS A POWER LAW?

The power law is a way to describe the relationship between two things, and states that a change in one thing results in a proportional change in the other thing. Take a square, for example: if you double the length of its sides, its area is increased four times, or by a power of two. Such relationships exist in all kinds of phenomena, from earthquakes to income levels.

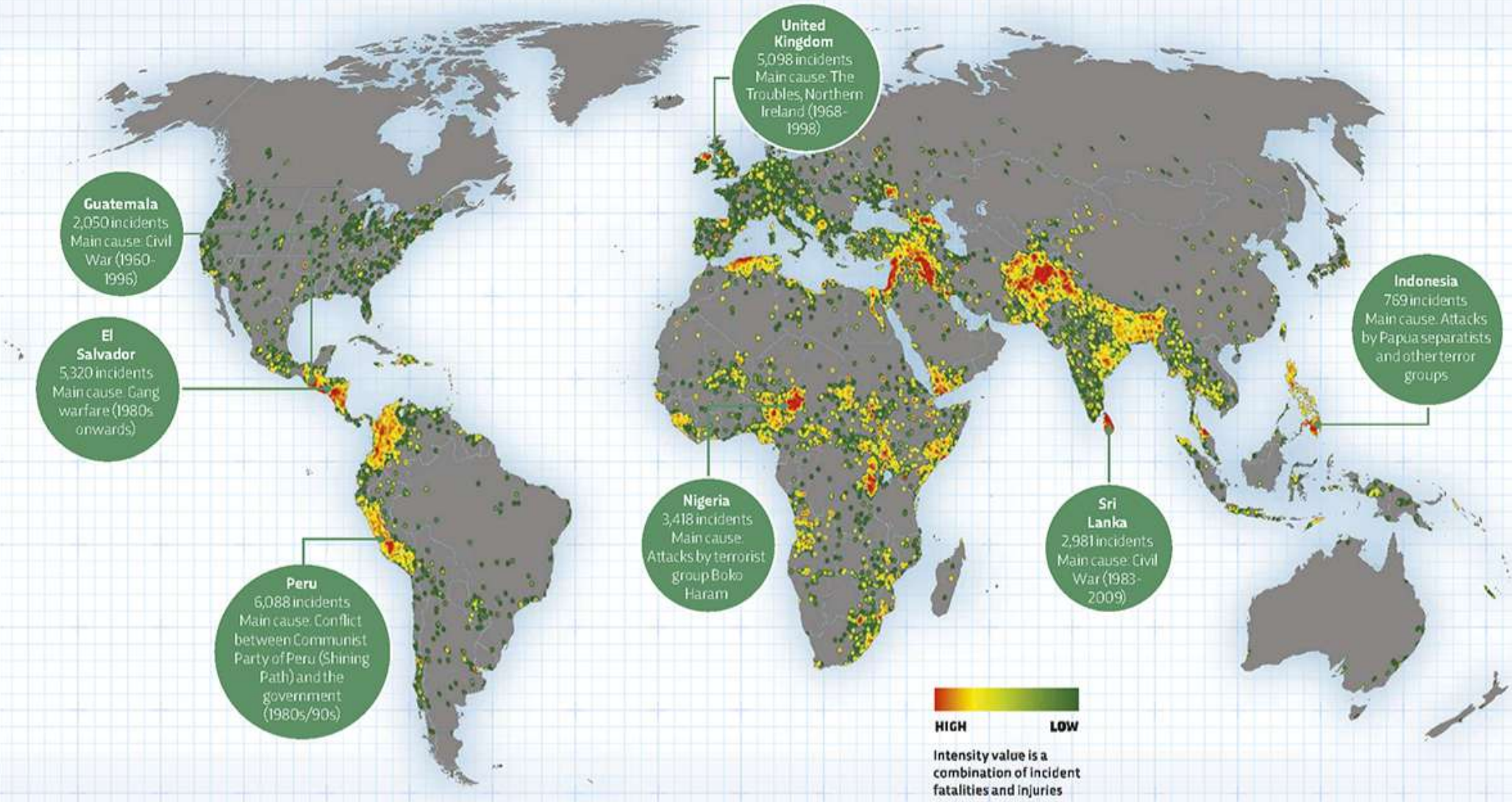
Plot these power law relationships on a graph and it shows that the most common things are those at the smallest scale, whether that's the level of income or the size of earthquakes. But there are also a few extreme 'events', like massive earthquakes or huge incomes. That's not true of other things: plot people's height or weight on a graph and you'll get a bell curve (below), in which most people are towards the middle and extreme 'events' are much less likely.

When it comes to terrorist events, a power law describes the relationship between the number of events and the number of people killed. It tells us that the 9/11 terror attack was not an anomaly – such an event is likely, statistically speaking, to occur again.



45 YEARS OF TERROR

Heat map showing all known terror attacks between 1970 and 2015



something familiar pops out: the power law. In other words, the distribution of the sizes of the groups is almost identical to the distribution in the scale of attacks, with lots of small ones and a handful of very large ones. After all, it's logical that the handful of large groups it predicts will be able to carry out far more destructive attacks than the vast number of small groups or 'clusters' of fighters.

"By cluster, we don't mean that the members walk around in a bunch, like kids in a playground," says Johnson, "but that they are coordinated in some way, such as by some means of modern communication. So it can apply to a cluster of people in the desert during the Iraq era, but it also applies to more tech-savvy groups of terrorists located in different places."

KEY DATA

Although it's impossible to know the size of a cluster carrying out attacks, the researchers can get data on the online individuals who support a cause or ideology. In fact, the data is freely available, as most groups are visible online to encourage new recruits.

Johnson and his colleagues studied pro-ISIS groups that share information, such as advice on financing terror attacks or how to avoid drones. Facebook aims to shut extremist groups down quickly, but pro-ISIS groups seem to be more prevalent on other online platforms. In a study of open-access information on VKontakte, based in Russia, Johnson found 196 pro-ISIS groups with over 100,000 followers. Groups were shut down within weeks, but the members would simply form a new one or join another existing one. It's these groups that followed the power law in their scale. And this fluid online world of ISIS support, where groups coalesce, disappear and reform, suggests a means to thwart them: split them up before they have time to form larger, more deadly groups.

Doing so won't eradicate terrorist attacks – it's likely nothing ever will. But it could limit the impact their attacks have. Hopefully 2019 will be a better year.

BBC WORLD SERVICE

Listen to an episode of *Discovery – Can maths combat terrorism?* bbc.in/2COwdWa

MAP SOURCE: GLOBAL TERRORISM DATABASE

BETTER CONNECTIONS

5G is set to launch next year to bring you more data at faster speeds

WORDS: **ROB BANINO**

If connected household appliances, autonomous cars and smooth, uninterrupted video calls are to become a reality we're going to need better mobile networks. Ones that provide faster, more stable connections with greater data-carrying capacities. And next year, we might start to get them.

The first fifth-generation, or 5G, mobile networks are expected to begin coming online in 2019 in China, South Korea, Japan and the US. Small-scale trials of 5G technology have already taken place in selected British cities, including Bristol, but the country's 5G networks aren't expected to start appearing until 2020.

5G networks use higher radio frequencies to carry more information, so while it might take you up to 10 minutes to download a movie on a 4G connection, it's claimed you'll be able to do it in approximately 30 seconds using 5G.

There's also a lower latency period with 5G signals, meaning less lag in software reactions – an improvement that's likely to enable the sort of real-time monitoring and response abilities required for autonomous vehicles and drones.

It's not all good news, however, because although 5G signals are faster and able to carry more data than 4G signals, they don't travel as far. So in order to build a practical 5G network more booster masts will be needed.

Click looks at the next generation of wireless tech
bbc.in/2OXA7Dk

GETTY

More data, faster downloads and more distractions with the new 5G networks

CYBER-SURVEILLANCE RAMPS UP

After ongoing allegations of Russian interference in America's presidential elections, it's worth remembering that the US has long acquired, used and misused information on enemies and allies. Indeed, many countries dabble in a bit of cyber-surveillance – and it looks set to continue in 2019

WORDS: **ALFRED W MCCOY**

Since President Trump's inauguration in January 2017, there has been a steady stream of media coverage highlighting Russia's use of disinformation and scandal in influencing the US presidential elections and the Brexit referendum in the UK. Yet, for well over a century, Washington used surprisingly similar clandestine tactics in its exercise of global power, from pacification of the Philippines in 1898 to recent cyber-surveillance of European allies.

The Philippines was just one of the sprawling empire of tropical islands that Washington took from Spain in 1898 – but it was the only one to challenge the US army, with guerrilla resistance and messianic revolts. Using America's advanced information systems of telephone, telegraph and automated tabulating (using a kind of proto-super-computer), the army formed the first field intelligence unit in its 100-year history. Under Captain Ralph Van Deman, dubbed the 'father of US military intelligence', the unit compiled detailed data on the appearance, finances and loyalties of every influential Filipino. Simultaneously, the American colonial regime created a constabulary that ruled through a total control over information, releasing scurrilous titbits to discredit dissidents and suppressing scandal to protect collaborators.

When the US entered the First World War in 1917 it had no intelligence service, so Van Deman was assigned to establish one. With a staff of 1,700 and 350,000 citizen operatives, his Military Intelligence Division launched intensive surveillance of domestic subversives – arguably the world's most extensive programme of the kind up to that time.

After retiring in 1929, Van Deman made his San Diego bungalow the epicentre of an intelligence exchange among military, police and private security, compiling dossiers on 250,000 dissidents and channelling classified information to citizen groups for public blacklisting. During the 1950 race for the US senate, Richard Nixon reportedly used Van Deman's files to smear his

Captain Ralph Van Deman, known as the 'father of US military intelligence'

rival for the California seat, launching his path to the presidency.

During the early years of the Cold War in the 1950s, Washington carried out 170 clandestine operations in 48 nations. Over the next 50 years, the CIA would covertly manipulate 80 elections worldwide and, when such efforts failed, promote many of the military coups that roiled more than 30 nations between 1958 and 1975. Under a secret treaty signed in 1946, the National Security Agency (NSA) and its British counterpart GCHQ built a worldwide signals surveillance through the Five Eyes coalition of the US, the UK, Australia, New Zealand and Canada, with its Echelon surveillance programme, established in the 1960s.

Iranian intelligence hacked into a CIA drone and forced it to land in public

WAR ON TERROR

With the launch of the so-called 'Global War on Terror' in 2001, Washington merged new tech such as electronic surveillance, biometric ID and aerospace innovation into a digital information regime. By 2008, the US army had collected more than one million Iraqi fingerprints and iris scans that its combat patrols accessed by satellite link to the US. At the same time, the Joint Special Operations Command's integrated database identified alleged Al-Qaeda operatives for elimination by drone strike. As Washington withdrew from Iraq, this tech migrated to Afghanistan, where US patrols regularly scanned Afghani eyes into an upgraded biometric automated toolset.

By the time Obama took office in 2009, the NSA had assembled the requisite technological toolkit of supercomputers and data farms to sweep up billions of communications worldwide while targeting specific individuals. In 2013, the New York Times reported that there were "more than 1,000 targets of American and British surveillance in recent years", including leaders of dozens of nations including France and Germany. Seeking diplomatic advantage over its allies, the US conducted "widespread surveillance" of world leaders during the G20 summit in Toronto in 2010. Three years later, NSA whistleblower Edward Snowden charged that "they even keep track of who is having an affair or looking at pornography, in case they need to damage their target's reputation".

In the marketplace of military ideas, even a crushing technological advantage is quickly lost. Washington was fast to weaponise the internet, forming its Cyber Command in 2009 and deploying computer viruses against Iran's nuclear facilities. Russia was not far behind, using cyberstrikes to cripple Georgia's computers in 2008 and later to disable Ukraine's electrical grid, leading NATO's 2016 summit to make the web a new domain for military operations.

Not only did a St Petersburg "troll factory" try to influence the 2016 US elections, but Russian hackers also stole some of the NSA's top-secret cyber tools. Showing the accessibility of cyberwar even to secondary powers, in 2011 Iranian intelligence hacked into the navigation of a super-secret CIA drone and forced it to land for public display in northern Iran.

The digital surveillance and cyberwarfare that seemed, just a few years ago, to provide wonder weapons for extending US global dominion have quickly become just another dangerous arena for military conflict, accessible to powers large and small. It's inevitable that in 2019, and years to come, cyber-surveillance will continue to be commonplace.

GETTY, US ARMY

BIG BROTHER

In China, 'good' behaviour wins you Brownie points, 'bad' behaviour gets the thumbs down. But is the technology in place to keep tabs on citizens?

WORDS: **ROGIER CREEMERS**

In recent months, China's social credit system (SCS) has been hitting the headlines. The SCS is often described as a unified project that constantly and automatically monitors and scores the behaviour of citizens, in order to sanction or reward them. But, so far, that description is incorrect. The SCS as it stands today is best understood as a bunch of different initiatives sharing a similar fundamental concept, but with different objectives and involving various public and private entities.

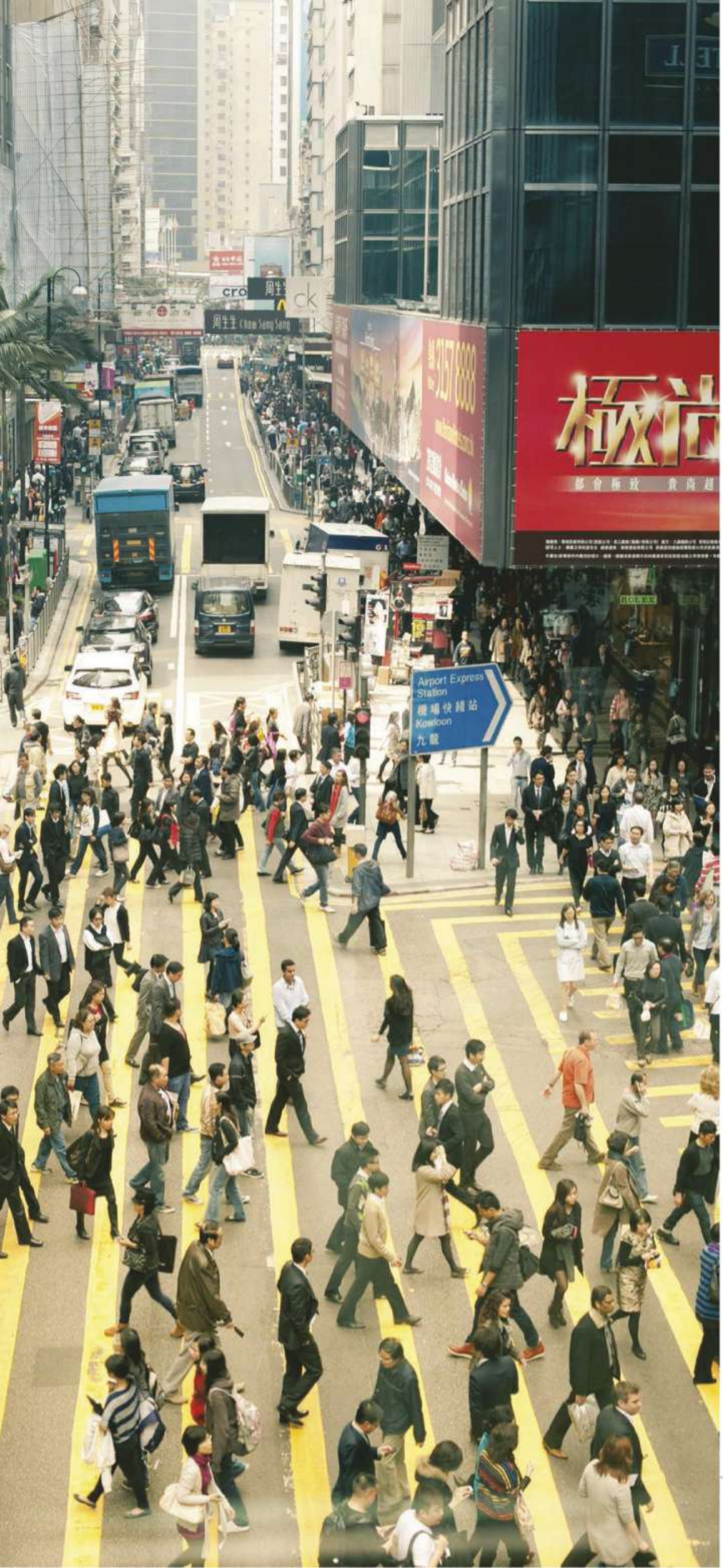
On the governmental side, work towards creating the SCS started around the turn of the century. As China increasingly became a market economy, the leadership grew more and more concerned about improper conduct in the marketplace. Abuses such as the sale of unsafe, counterfeit or substandard goods, and non-payment of debts or fines, caused considerable concern among market authorities. In response, they took initial measures to study the creation of a system that would use reputational sanctions and rewards to ensure trust in the economy. By 2014, both the scope and impact of the envisaged social credit system had grown enormously to include political discipline and cover benefit fraud by citizens.

The main operational side of this part of the SCS is a series of blacklists. The most important one is maintained by the Supreme People's Court, and lists individuals and businesses who have not complied with a court judgment against them. Aside from being publically named and shamed, blacklisted individuals and businesses are also hit with various sanctions, ranging from not being eligible for particular corporate offices and government loans to limits on air travel and star-rated hotels. And ministries have created more specifically targeted blacklists, from workplace safety to environmental protection. Civil aviation authorities, for instance, now blacklist individuals misbehaving on aircraft, barring them from future flights.

Ranging from not being eligible for corporate offices and loans to limits on air travel and star-rated hotels

To further complicate matters, local authorities also have blacklist systems of their own, addressing matters falling under their jurisdiction. These vary considerably from place to place. In Shenzhen, for instance, facial recognition cameras log anyone crossing the road when the traffic lights are green for vehicles. Those caught five times end up on the blacklist. In short, the blacklist system is binary: you're either on one or you're not.

But the technology is still being developed. National identity databases for individuals and businesses are in the pipeline, but don't currently exist. This means that as Chinese society grows increasingly mobile, it has been difficult to track alleged offenders across regional borders, but also to transmit healthcare information from one locality to another. Quantitative scores are currently not used at the national level, although some localities have experimented with them. Rongcheng, a



ALAMY

small city in the eastern province of Shandong, for instance, categorises its citizens from AAA to D, influencing whether they will be eligible for government jobs or subsidies.

WEB RATING

A rather different kind of social credit system emerged from China's rapidly expanding online economy. For years, China's central bank had tried to expand private credit opportunities, yet China's traditional banking sector remained mostly focused on financially supporting government policies, while the Chinese economy remained largely cash-based. Only a few held credit cards. So, China's burgeoning internet companies had to create mobile payment systems to support their business.

Subsequently, the central bank launched a trial scheme in which eight private businesses, including financial subsidiaries of online giants Alibaba and Tencent, were allowed to develop credit scoring mechanisms. Alibaba's programme, Sesame Credit, became the best known of these experiments. Combining elements of a rating scheme and a loyalty programme, it issued a score between 350 and 950 to users. While a low score didn't result in punishment, a high score came with rewards ranging from visas being processed to easier access to loans. Many users also published their Sesame scores on their public profile or even in Alibaba's online dating service.

Sesame credit shouldn't be confused with the official government credit system. In fact, concerns about partiality and conflicts of interest led the central bank to refuse permanent licences to all eight businesses. Instead, the eight jointly established a credit rating company in collaboration with an intermediary organisation with the backing of the central bank.

Yet, at the same time, the focus on moral conduct in both the government and private credit systems does reflect a form of paternalism, strongly present in current Chinese political culture. High-level policy documents indicate the leadership is convinced that increasing datafication will help it to influence citizen behaviour, which could resolve its issues with regulating society and the economy. It remains to be seen whether that actually happens.

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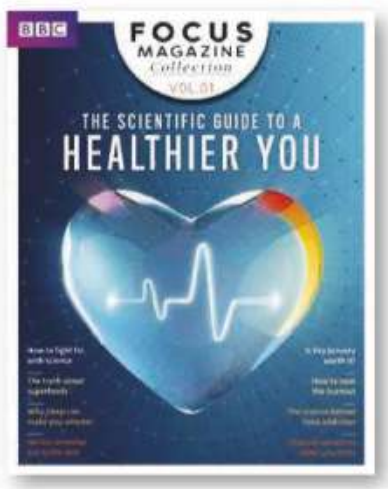

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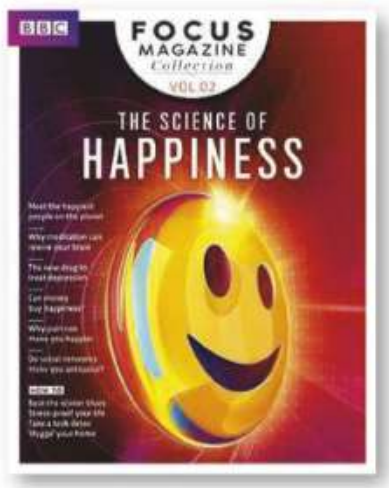

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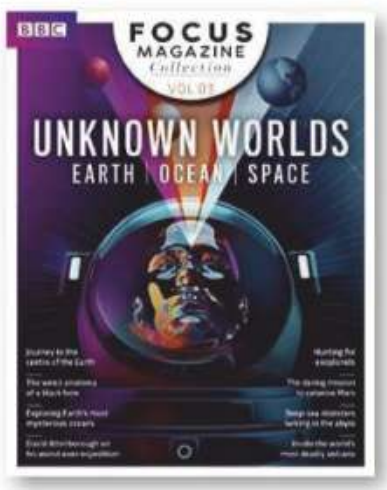

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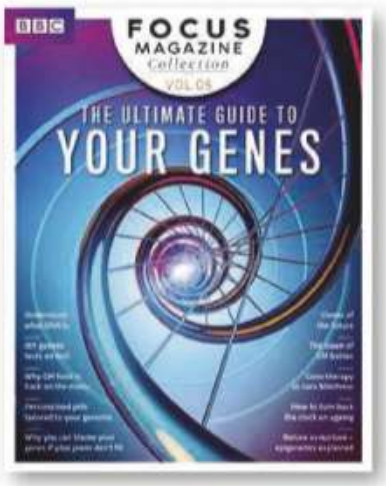

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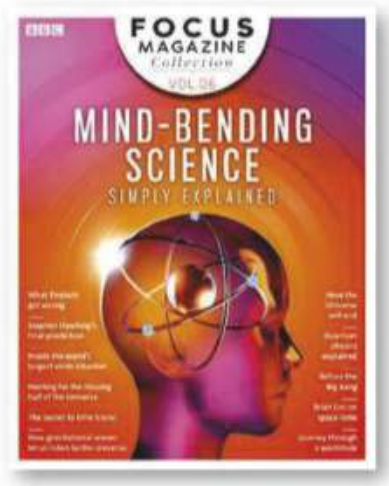

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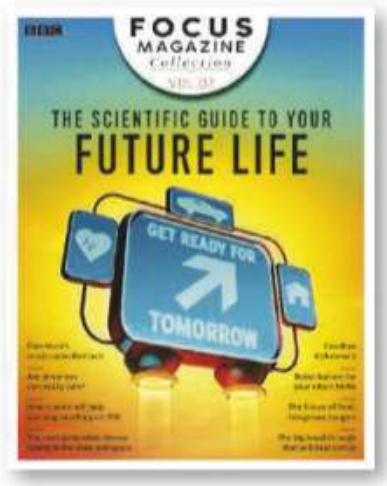

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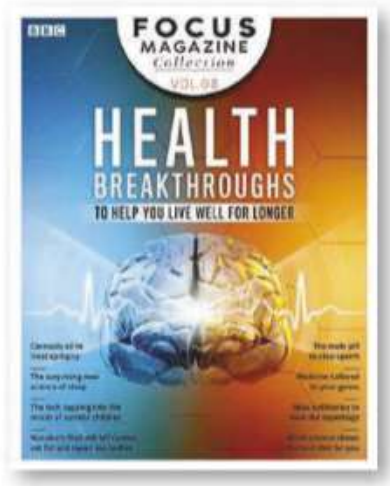

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"In 2019, the research icebreaker Polarstern (part of the MOSAiC expedition) will drift across the Arctic Ocean, collecting data on a huge variety of Arctic science topics."

HELEN CZERSKI
physicist, oceanographer and BBC broadcaster

"New techniques for efficiently recycling mixed plastics using bacteria could be an important breakthrough in 2019."

PROF MARK MIODOWNIK
materials scientist and BBC broadcaster

"8 million tonnes of plastics end up in our oceans every year. The actions of one may seem trivial, but the knowledge that there are people doing the same thing – that really does have an effect."

DAVID ATTENBOROUGH
BBC broadcaster

PLANET EARTH IN 2019

GETTY

THE PLASTIC AGE

This year we had an epiphany: our lives and the planet are literally filling up with plastic. Now that we're starting to get a grip on the scale of the problem, what can we do about it?

WORDS: **HELEN SCALES**

Maybe it was the baby sperm whale on the BBC's *Blue Planet II* with a plastic bucket snagged in its mouth. Or the photograph of a seahorse clutching a drifting cotton bud, or perhaps a visit to a rubbish-strewn beach? Whatever it was that awakened you to the problem, there's no doubt that in recent months more people than ever have been shocked into noticing the issue of plastic pollution.

As scientists venture out to gauge the scale of the problem, the plastic facts are being laid bare: a trillion plastic fragments frozen into the Arctic sea ice; a plastic bag at the bottom of the Mariana Trench, almost 11 kilometres down at the oceans' deepest point; each square metre of a riverbed in Manchester infested with half a billion microplastic particles, the highest concentration measured anywhere on the planet so far. Plastic is showing up in the food we eat, the water we drink, even the air we breathe. The details quickly become overwhelming but the message is loud and clear: the world, and our daily lives, are filling up with plastic. What's less clear is what damage this is causing to wildlife and people, and what we should do about it.

"Our picture of the environmental impact is still patchy," says Richard Thompson, Professor of marine biology at Plymouth University, who published a landmark paper in 2004 revealing the widespread pollution of the oceans with microplastics, under 5mm in size. A major health concern is the possibility that those plastic fragments percolate through ocean food webs and end up in the seafood we eat. Many studies have already shown that microplastics are eaten by hundreds of aquatic animals, including fish, krill, plankton, seabirds, crabs, worms and corals. Some species even seem to prefer plastic over their normal food, perhaps because of the way it smells. And it's no surprise that having a gut-full of indigestible plastic tends to make life difficult: animals grow more slowly, run down their energy reserves, reproduce less and many simply give up and die.

THE FOOD CHAIN

Part of the picture that's still fuzzy is whether microplastics get passed on as animals eat each other. Does a shark or a seal inherit a plastic payload from their prey?

Several studies are beginning to suggest this could be the case. In the Celtic Sea, out of a

ALAMY

As more plastic finds its way into the oceans, more of it ends up in the intestines of sea life

THE NEW 'PLASTICS'

In the next few years we could start seeing traditional oil-based plastics increasingly replaced by biodegradable plastics, including some made from unusual materials

SHRIMP SHELLS AND SILK

A major waste from the food industry is chitin, the main component of shrimp, crab and lobster shells. Researchers at Harvard University have combined it with silk protein to form a degradable plastic they've named Shrilk.

MANGOS

Mango seeds and skins are being investigated as possible sources of bioplastics for use in plastic bottles and cups.

WOOD

Tough woody material from trees called lignin is a byproduct in the paper-making industry that's usually burned. Scientists are now feeding it to genetically-modified bacteria, which break it down into molecules for making bioplastics.

SEAWEED

Dutch designers have developed a bioplastic made from algae, which can be used in 3D printers.

MUSHROOMS

A New York-based firm is developing foam packaging from the thread-like roots (called mycelium) of mushrooms, as a replacement for polystyrene.

HAIR

An art student in London has made a chair from human hair. A single chair was made from three full bin bags of hair, swept from the floors of hairdressers and glued together with another bioplastic.

sample of 109 plaice, just over half had fragments of microplastics in their guts. Researchers also found similar traces inside sand eels, making a tentative link between these plankton-feeders and the flatfish that eat them. In Australia, scientists fed microplastics to little beach-dwelling crustaceans, known as sand hoppers, then fed those hoppers to small fish called gobies. Again, the plastics were passed one step up the food chain. Whether this has any lasting impact on the eels, plaice or gobies is an unresolved matter. And while we're still a long way off understanding how microplastics impact simple duos of predators and prey, we're even further from getting a handle on what's going on across entire, complex ecosystems.

"It's really important that we make the right decisions now and we don't jump to knee-jerk reactions"

COMING BACK TO HAUNT US

If plastics are contaminating aquatic food webs, are they also getting into our food? There's no doubt that when you eat a bowl of moules marinière, you could be consuming microplastics that the mussels pick up as they filter seawater. A recent study found plastics inside mussels on supermarket shelves and living all around the British coasts. The question is does eating them do us any harm? Well, besides the plastics themselves, there's the chemicals they're coated in. Chemicals such as phthalates and bisphenol A are added to plastics to make them more flexible, transparent and durable, and when they leach off they're known to disrupt hormones in vertebrates.

As yet, no major medical horrors have been uncovered, but it's not easy proving a link between health problems and plastics creeping into our diets. "If it was suddenly shown that plastic particles, in some shape, form or dimension, had the same effect as asbestos, that would, of course, accelerate the process

NANOPLASTICS

A bigger problem than microplastics?

Nanoplastics, smaller than a micron (1000nm), could be floating through the oceans and piling up on the seabed, but at the moment there's no way of detecting them. "The smaller it gets, the less we know," says professor of marine biology, Richard Thompson. Scientists are developing automated machines to trace the chemical signatures of these tiny plastics, so we should know more soon. Already there are fears that nanoplastics could cause even bigger problems than microplastics because they're likely to hold more chemical contaminants on their relatively large surface area and there's a possibility they could get inside living cells. In a lab study, when zebrafish were fed nanoplastics, the particles moved into the fishes' blood and built up in their nervous systems. This changed their behaviour and possibly caused brain damage: the fish explored their surroundings less and ate more slowly. Contaminated female zebrafish even passed on nanoplastics to their young, via the egg yolk. Another study shows that animals may produce nanoplastics. Antarctic krill fed fluorescent green microplastics, ground them down in their guts and glowing nanoplastic particles appeared in their faeces. It seems likely that krill are doing something similar in the wild.

towards change," says Thompson. "We just don't know that at the moment."

Thompson worries that if we wait until we fully understand the environmental and human harm of ocean plastics, then decision-makers may rush towards solutions that look tempting but could end up causing more trouble. "It's really important that we make the right decisions now and we don't jump to knee-jerk reactions." He points towards the focus on banning plastic drinking straws as a misguided effort. "It's great to encourage people to do without them," he says, "but on its own it isn't going to solve the problem and some would argue it's a bit of a distraction."

Thompson is convinced the key to finding the right ways to solving plastic pollution will be to bring together teams of experts from different disciplines. It won't just be ecologists and toxicologists studying the impacts of plastics, but material scientists working on making them easier to reuse and recycle, and psychologists who understand what changes people's habits.

ABOVE: Water samples can show the extent of the spread of microplastics in the oceans

BELOW: Mussels feed by filtering seawater and so inadvertently consume microplastics

"We need to change our relationship with plastic," he says.

Thompson takes a positive outlook and believes we've reached a crucial stage. "Things have never been as aligned as they are now," he says. Not only are the public aware and demanding changes, he points out, but policy makers are eager to respond to those demands, as are industry leaders, either because they see a financial threat if they don't act, or because they see an opportunity if they do.

There's no doubt that the public are engaging with the plastic debate more than any other modern environmental threats. "People can see this marine litter and they can identify with it," Thompson says. Of course, there are other, less visible problems to deal with, such as climate change, but he argues that solving the plastic problem could set a good example of how to get things right. He likens ocean plastics to the issue of CFCs and the ozone layer 30 years ago. "There's an environmental challenge here," he says. "I think it's a problem we can solve." F

GETTY X8

CREATING EDENS

China is the future of global conservation, according to Sir Tim Smit, the maverick businessman and environmentalist who created the Eden Project

WORDS: **PATRICK BARKHAM**

Forget those hoary myths about China building a coal-fired power station every week, says Sir Tim Smit, the man behind the Eden Project in Cornwall. In fact, he predicts, the country will soon lead the global environmental movement. "China is the most extraordinary example of development in the history of humankind. Their achievements are shockingly underplayed in the West. In my view, the repair of the environment is seen as one of the cornerstones of China's self-confidence and its emergence into its next phase – being the dominant civilisation in the world."

For the past two decades, Smit has been best known for the Eden Project. Born in the Netherlands, he studied at Durham University intending to become an archaeologist, but instead made his fortune as a composer/producer for the likes of Barry Manilow and The Nolan Sisters. After 'retiring' to Cornwall he set his sights on creating a "great green cathedral" to plants in an old china clay pit near St Austell.

Smit was convinced that "a lost world in a crater would appeal to anyone who's ever been 12". More remarkably, he convinced everyone else it would too and managed to raise the £86 million it would cost to get the Eden Project built. He appears to have been right: since it opened in 2001 the Eden Project has welcomed more than 19 million visitors.

Smit is currently talking more about China than Cornwall, though. He has long pondered creating 'Edens' around the world, but in 2018, he took the plunge and began to develop projects in China, Costa Rica, California, Dubai, New Zealand, Tasmania and the Seychelles.

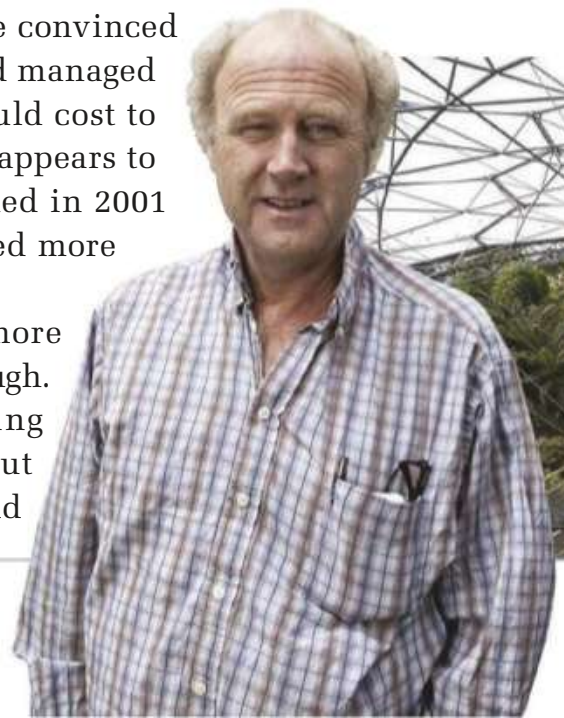
SEEKING SOLUTIONS OVERSEAS

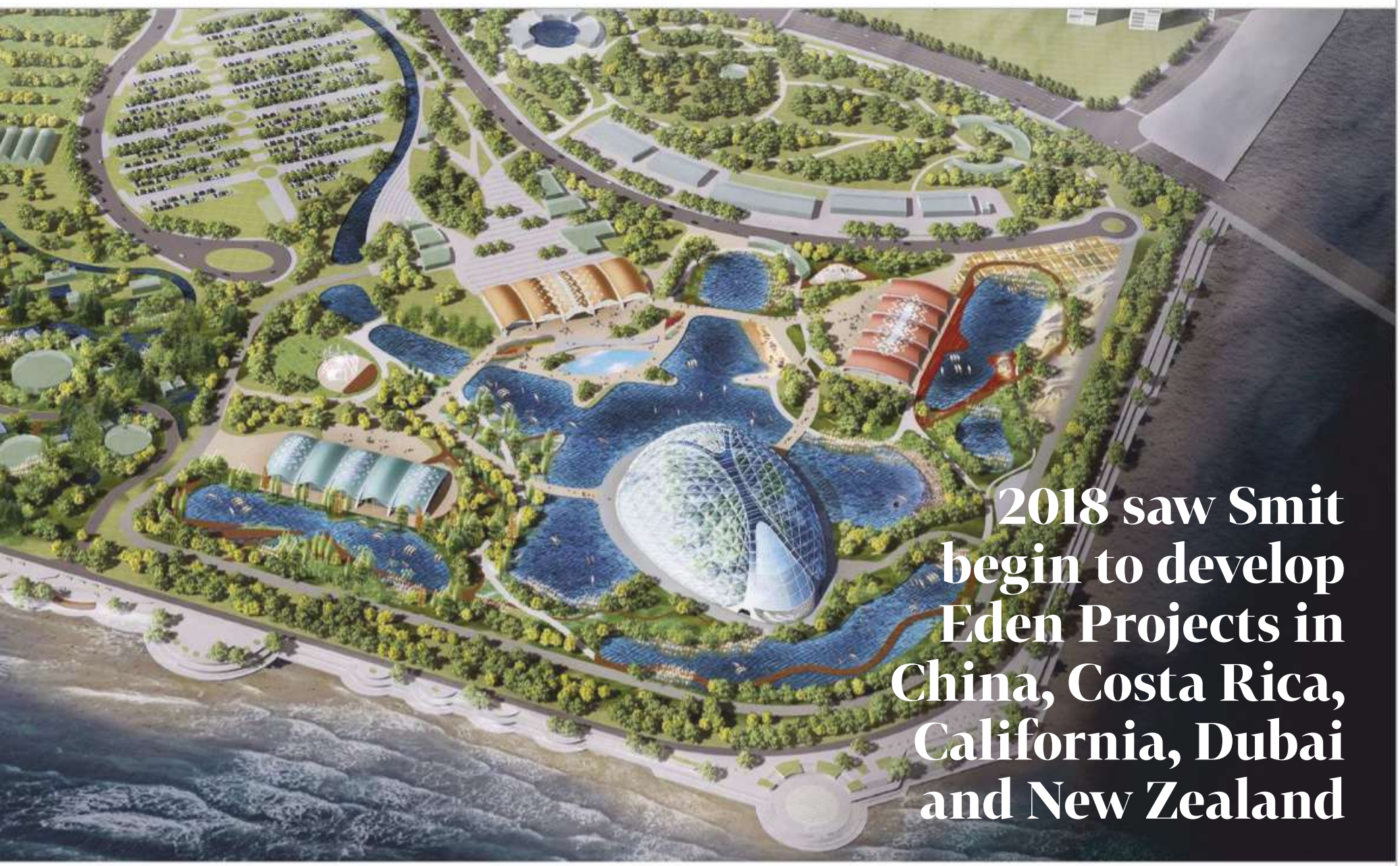
Sceptics may wonder how Edens in places such as Dubai and China can rescue the planet. But Smit is willing to explain.

Museums, exhibitions, zoos – all the great scientific institutions – are failing to save the world, he argues, and, by his own admission that includes the solitary Eden Project in Cornwall. If these organisations were "even half as good as we all claim to be, the world would be a different place because the educational messages that we think we're so successful at transmitting would've changed people's behaviours." But the uncomfortable truths about the sixth great mass extinction, climate change, pollution and soil erosion are not getting through.

Smit's solution: a network of Edens on every continent is less of an ambition to educate and more of an attempt to study, "to get the benefit

Sir Tim Smit's vision for the Eden Project was "a great green cathedral" to plants. It opened to the public in 2001





2018 saw Smit begin to develop Eden Projects in China, Costa Rica, California, Dubai and New Zealand

EDEN PROJECT, SHUTTERSTOCK, GETTY

of a whole range of cultural responses to the environment so we can learn from each other about what is working where," he says.

Smit's Chinese work began after he read an interview with a Chinese businessman who said that the Eden Project was the most exciting thing he'd ever seen. After hosting delegations from all around China, Smit was invited over and is now launching three and a half projects in the country.

The first, which is expected to break ground next June, is intended to highlight the marine environment. Its waterside position in the city of Qingdao is equivalent, claims Smit, to the site of the Sydney Opera House. But, crucially, like Eden in Cornwall, it's on 'poisoned ground' that Smit hopes this project can restore.

The second project, in Yan'an city on the Yellow River, will showcase the importance of soil. Locals realised that if they felled trees, their clay soils turned into mud, washed into the river and raised its bed, causing devastating floods. Yan'an is also famed for being Mao Zedong's revolutionary HQ and the end-point for his Long March. As Smit remarks wryly: "We want to become the second most famous tourist destination in Yan'an." Smit's third Chinese venture is most recognisably 'Eden': a new centre bringing together food and farming in two giant quarries in Tianjin, near Beijing. And his final 'half' project is an Eden China HQ in a vineyard growing on a 35-acre landfill site.

Unsurprisingly, Smit's meetings with the Chinese politicians and private companies funding these Eden schemes have given him a more nuanced understanding of the country and its ambitions than the popular perception of them in the West allows. As well as China's massive solar industry, Smit says the country has planted more trees in the past three years than the rest of the world put together. It's aiming to plant new forests the size of Ireland in 2018 alone. Smit doesn't presume to precisely describe the mindset of China's leaders but perceives "a blind faith that its people are clever enough to sort this [global environmental crisis]. And now is the time." China, he thinks, "will be good for the world".

Work is expected to begin on the first Chinese Eden Project, located in the seaside city of Qingdao, in 2019

MINING NEW DEPTHS

In 2019, the world's first commercial deep-sea mine is due to open. But are regulations in place to protect the sea floor?

WORDS: **HELEN SCALES**

Every time you pick up your smartphone, you hold in your hand a veritable periodic table of elements. Among the metals under the casing there's cobalt, nickel and indium, plus traces of 16 of the 17 so-called rare earth metals. They're all dug up in mines dotted across the globe, from the Democratic Republic of Congo to the Philippines, Chile and China. One day, perhaps in the not too distant future, smartphones could contain metals that come not from land but from the deep sea.

Mining the deep isn't a new idea. For several decades, mining corporations have eyed up the mineral riches that lie in Davy Jones's Locker. But it's always been too expensive to operate machinery kilometres beneath the waves and metal prices too unsteady to make it worthwhile. Now, though, the first deep-sea mines are closer than ever to opening.

In 2018, a test of deep-sea mining methods was carried out in the waters off Japan. In 2019, the world's first commercial deep-sea mine is due to open off Papua New Guinea. And there's growing interest in mining vast swathes of open ocean, known as the high seas, that lie far from shore and no countries own. Currently, mining corporations are prospecting 1.3 million square kilometres of the high seas, roughly the area of Alaska. Before any mines can open, however, a new rule book needs to be written, laying down international regulations on how mining will operate. The rules that book will contain are currently being negotiated with the aim of releasing a final list by 2020. When that happens, the first seabed mines in the high seas could begin operating.

TECH'S DEEPENING REACH

The main targets for deep-sea mining are potato-sized rocks, known as nodules, that lie scattered across flat abyssal plains. Miners are also prospecting underwater mountains, called seamounts, and the tall chimneys of hydrothermal vents. The extraction system will involve gargantuan machinery bristling with enormous drill bits and operating remotely, thousands of metres down, to scrape off the metal-rich crusts of seamounts and crush vent chimneys. Machines with giant caterpillar tracks will crawl across the seabed scooping up nodules. Then, rocky slurry will be pumped up to ships on the surface for processing.

BBC RADIO 4

Listen to *Into the Abyss* which discusses deep-sea mining **bbc.in/2qjmHD1**

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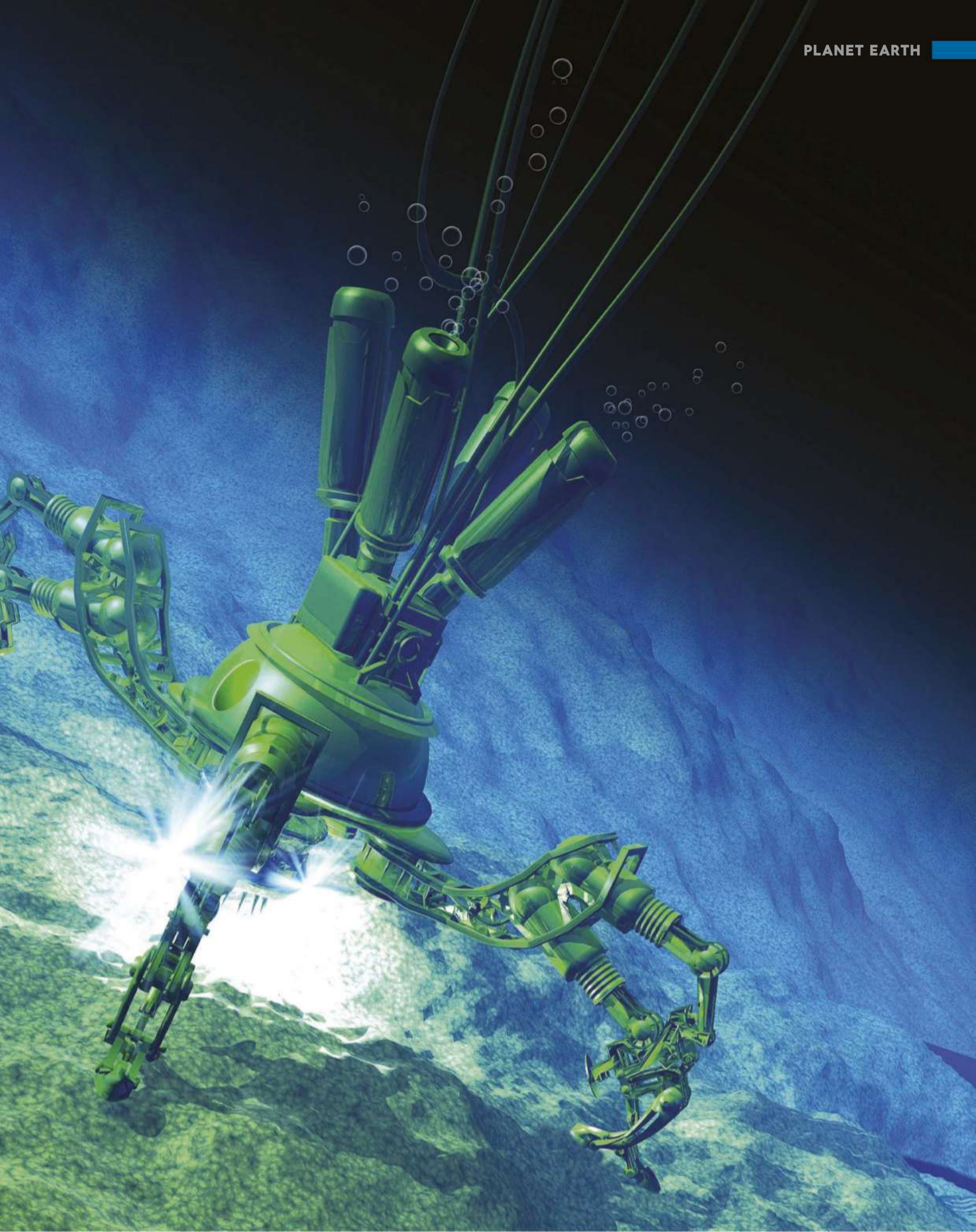


Driving this new rush for the deep is the tech industry's rising demand for metals, plus fears that traditional sources from land-based mines could be running low. Some experts also claim that tackling climate change and phasing out fossil fuels will be impossible unless the deep sea is mined for metals to make solar panels, wind turbines and electric car batteries – a single car battery currently needs 9kg of cobalt. As a consequence, corporations are keen to secure new supplies of metals.

"It's a few people sensing an opportunity that, if they're the first movers, they can really get ahead of the game," says Kristina Gjerde, Senior High Seas Advisor to the International Union for the Conservation of Nature and co-lead for the Deep Ocean Stewardship Initiative.

There's more at stake than just the metals lodged inside these deep-sea deposits, though. Nodules, seamounts and hydrothermal vents are home to extraordinary lifeforms unlike anything we see on land, and only a fraction have so far been discovered and studied.

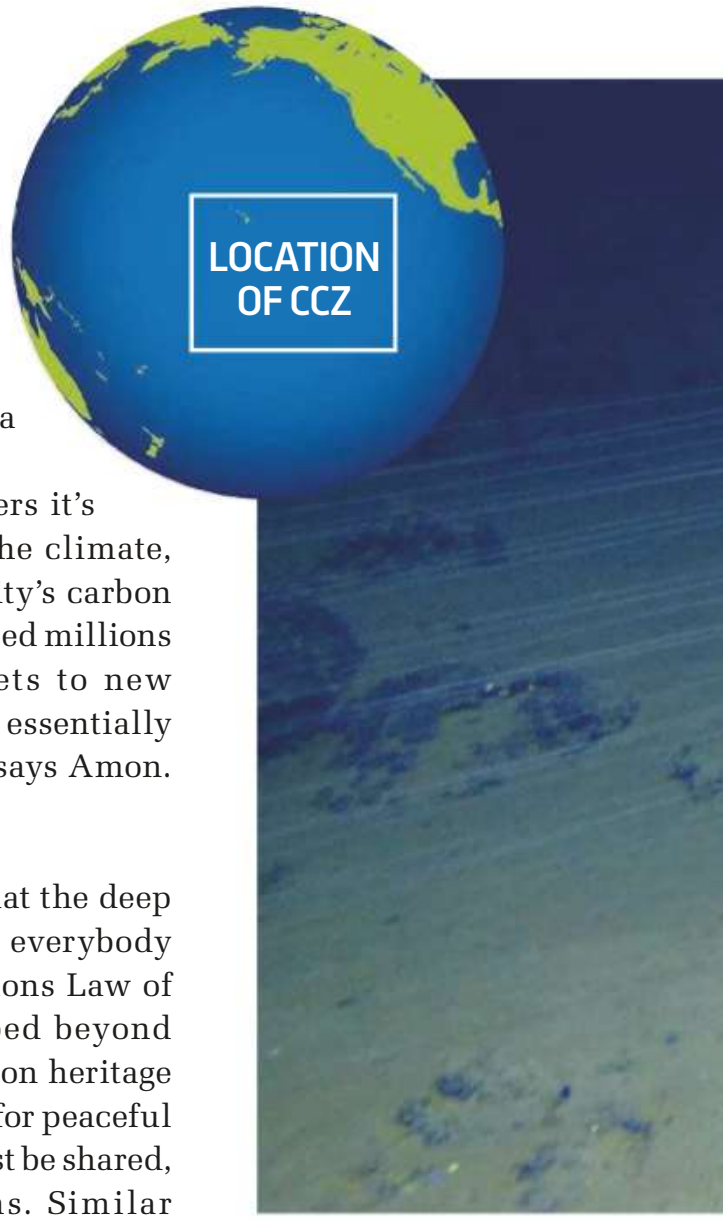
"Most people view the ocean in this two-dimensional way," says Dr Diva Amon, a deep-sea biologist at the Natural History Museum in London. "It's just a blue expanse." And yet, covering 60 per cent of the Earth's surface and four kilometres deep on average, the deep sea forms the biggest living space on the planet. Amon describes a recently discovered Pacific seamount covered in corals and sponges, which live for thousands of years. "It looks like something out of a Dr Seuss book," she says.

As well as the biological wonders it's home to, the deep sea regulates the climate, absorbs roughly a third of humanity's carbon emissions, supports fisheries that feed millions of people and could hold secrets to new pharmaceuticals. "Our deep sea is essentially responsible for keeping us alive," says Amon.

WHAT'S MINE IS YOURS

Complicating matters is the fact that the deep sea legally belongs to nobody and everybody at the same time. The United Nations Law of the Sea Treaty declares the seabed beyond national boundaries as the 'Common heritage of humankind'. It can only be used for peaceful purposes and part of any profits must be shared, especially among poorer nations. Similar treaties apply to Antarctica, the Moon and space.

The International Seabed Authority (ISA), a small organisation based in Kingston, Jamaica, is charged with looking after the seabed on behalf of humanity. It's up to the ISA to decide how to share out any wealth generated in the deep, something that needs to be worked



Polymetallic nodules protrude from the muddy bed of the Clarion-Clipperton Zone. Both the mud and the nodules serve as habitats for the rare forms of sealife that dwell there

DEEP MINING TARGETS

Polymetallic nodules

LOCATION: Abyssal plains

MAIN DEPOSITS: Clarion-Clipperton Fracture Zone and the Peru Basin in the Pacific

DEPTH: 4,000-5,500m

METALS: Manganese, nickel, cobalt, copper, plus traces of molybdenum, lithium and rare earth metals (REMs)

KEY FEATURE: 5-10cm spherical rocks that grow as metals settle out of the water at a rate of 1 to a few mm per million years

WHAT LIVES THERE: Octopuses, corals, sponges, brittle stars, sea cucumbers and maybe foraging whales

Cobalt-rich crusts

LOCATION: Seamounts

MAIN DEPOSITS: Western equatorial Pacific

DEPTH: 800-2,500m

METALS: Manganese, cobalt, copper and nickel, plus traces of REMs

KEY FEATURE: The metal-rich crusts grow around 1-5mm per million years

WHAT LIVES THERE: Corals, sponges, starfish, sea urchins, long-lived fish

Seafloor massive sulphides

LOCATION: Hydrothermal vents

MAIN DEPOSITS: Mid-ocean ridges, subduction zones

DEPTH: 800-5,000m

METALS: Copper, zinc, lead, cobalt, silver and gold, plus traces of REMs

KEY FEATURE: Around 80 per cent of animals living on hydrothermal vents are found nowhere else on the planet. It's also thought life on Earth could have first evolved in hydrothermal vents

WHAT LIVES THERE: Yeti crabs, Hoff crabs, octopuses, scaly-foot gastropods, giant tube worms

Polymetallic nodules contain manganese and iron

GETTY, ALAMY, CRAIG SMITH/DIVA AMON/ABYSSLINE PROJECT

PROTECTING THE CCZ

Miners have their eyes on the bounty of the Clarion-Clipperton Fracture Zone

At the bottom of the Pacific Ocean between California and Hawaii, stretches the Clarion-Clipperton Fracture Zone (CCZ), a 6 million square kilometre muddy plain that's covered in trillions of polymetallic nodules. It's a major focus for deep-sea mining prospecting.

Dr Diva Amon was part of a team that catalogued a wealth of sealife in parts of the CCZ where scientists had never been before. "Just over half of all the animals that we brought up were completely new to science," she says. Amon and her colleagues revealed this to be one of the most diverse places in the deep sea.

As well as the seabed, the nodules themselves also form an important habitat. They're the only hard surface available for corals and sponges to grow on and scientists have spied deep-sea octopuses laying eggs on the stalks of nodule-growing sponges.

Recently, another research team found thousands of grooves in the muddy seabed 4,000m below the surface that could be being dug by deep-diving whales. If whales are hunting for food in the floor of the CCZ, it adds another challenge to making sure mining doesn't impact the ecosystem.

The International Seabed Authority is also legally bound to ensure that mining causes no major ecological damage

out before any mines open. The ISA is also legally bound to ensure that mining causes no major ecological damage. The impacts of mining on deep-sea life, and the vital services it provides, are not yet fully understood although chances are they could be severe and, in some cases, irreversible. Nodules and seamount crusts take millions of years to form and mining machinery will kick up muddy plumes that could drift tens and hundreds of kilometres, smothering delicate creatures on the seabed and in open water.

"We need that fundamental science to be able to make informed decisions about whether we should or should not go ahead with deep-sea mining," says Amon. Plans are being drawn up to protect delicate deep-sea ecosystems including areas that will be off limits to mining, but the science isn't clear on whether these measures will work.

Amon and many others think that the rush to open mines should slow down while more science is gathered. In 2018, the European Parliament called for a global moratorium on deep-sea mining until the risks are fully weighed up. "We can't manage what we don't understand and we can't protect what we don't know," says Amon.

It's also unclear just how important the deep-sea mines will be in supplying the world with metals. "I think we do need to ask critical questions," says Gjerde. "Is this the time to go into the vast unknown in order to get some relatively short-lived metals that we think we need for the green revolution?"

Eventually, we could all end up facing a choice in the gadgets and cars we buy. Perhaps, in the years to come, a circular economy will develop in which metals won't be used just once then thrown away, but recycled and reused many times. Or maybe we'll see labels on products showing the origins of metals used inside them – perhaps brown labels for metals from mines on land and blue labels for metals brought up many kilometres from the bottom of the sea.

FASTER DELIVERIES

Melting sea ice around the North Pole is a catastrophe for everyone… except shipping companies

WORDS: **ROB BANINO**

Thanks to the decline in Arctic sea ice caused by global warming, the Venta Maersk became the first commercial container ship to successfully navigate the Northern Sea Route. The 42,000-tonne vessel, carrying a cargo of fish from Russia and electronics from South Korea, docked in St Petersburg on Friday 28 September 2018, 37 days after setting sail from Vladivostok.

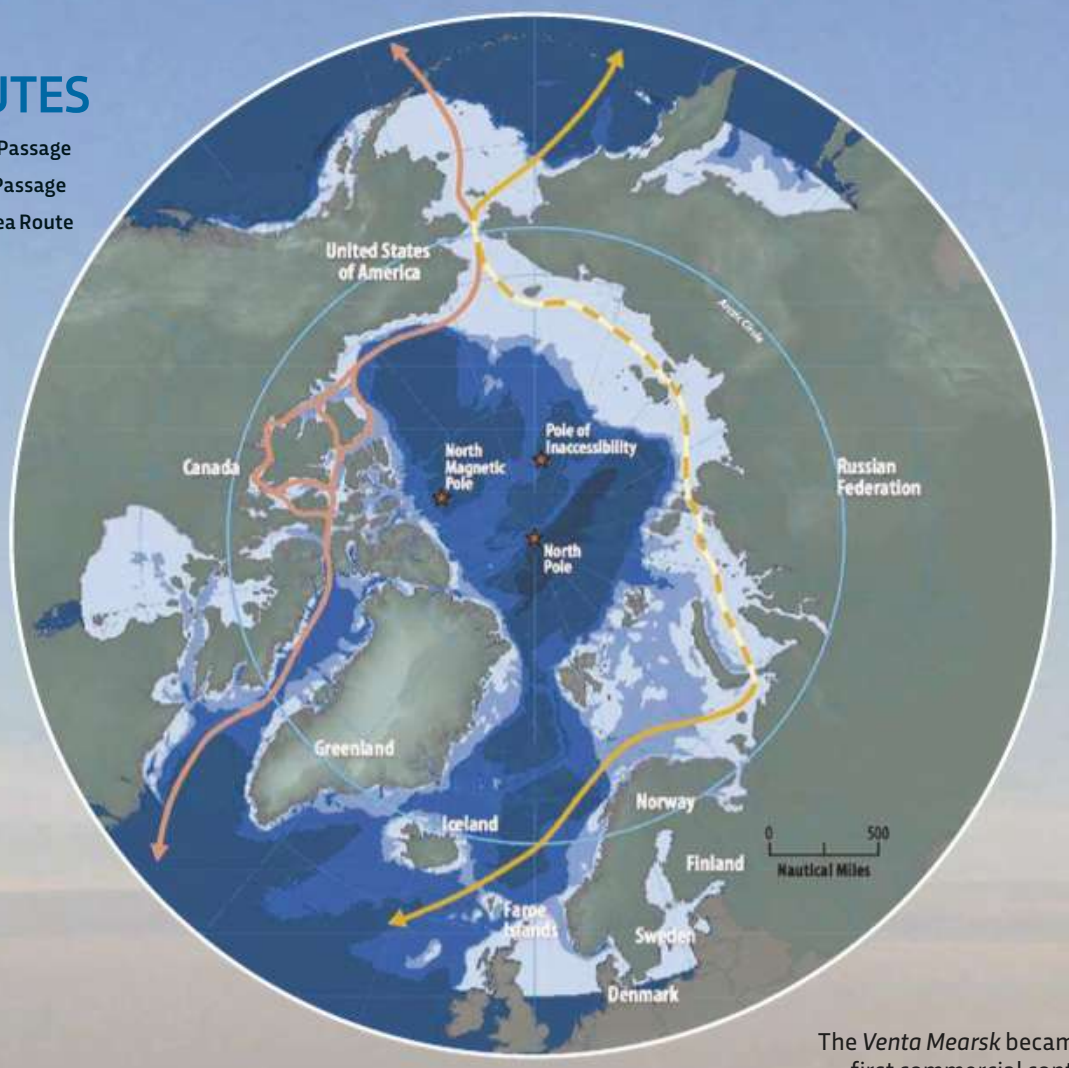
The Northern Sea Route runs across the top of Russia and could provide a shipping lane between Europe and Asia that's 8,000km shorter and approximately two weeks faster than the alternative course via the Suez Canal, India and Malaysia. But until now, sea ice has made it impossible for cargo vessels to complete the passage.

It's not good news at all, though. Large vessels such as the Venta Mearsk passing through the route regularly will cause additional damage to the region. Particulate emissions from the fuel burnt in the ships' engines will settle on what ice is left, causing it to absorb rather than reflect heat from the Sun and increasing the rate at which it melts.

MAERSK, WIKICOMMONS

SEA ROUTES

Northwest Passage
Northeast Passage
Northern Sea Route



The *Venta Mearsk* became the first commercial container ship to successfully navigate the Northern Sea Route

COUNTING FISH

So-called 'environmental DNA' is helping conservationists keep track of marine species

WORDS: **HELEN SCALES**

As plenty of scuba divers will tell you, they rarely find themselves in exactly the right place at the right time to spot a whale shark, a basking shark, a hammerhead or any other shark species gracefully gliding by. Shark researchers face this same dilemma in their studies. They'll spend days and weeks at sea hoping for shark encounters. Conventional surveys involve scuba diving, setting fishing lines to catch sharks or lowering video cameras into the sea, along with chunks of bait that sharks might come up and chew. But now there's a much quicker and cheaper shark tracking tool – a bucket-full of seawater.

"The ocean is a soup of DNA," says Judith Bakker, a postdoctoral researcher at Florida International University. "Everything from small plankton to gigantic whales are constantly leaving behind traces of DNA."

Small snippets of genetic material come from mucous, skin cells, urine and faeces. Over the last 10 years, scientists have worked out how to gather these small DNA fragments – known as environmental DNA or eDNA – and convert them into a powerful tool to track species without actually seeing them.

In a study spanning the Pacific Island of New Caledonia and various spots in the Caribbean, Bakker screened water samples for shark eDNA. "A couple of years ago, people were very sceptical," she says. The eDNA technique was originally developed to study soil microbes and later in streams and ponds, searching for invasive species like American bullfrogs. It took a while to catch on with marine scientists, as they assumed there wouldn't be enough DNA to detect species swimming through these vast bodies of water. But Bakker and her colleagues took on the challenge and eventually fine-tuned the technique for detecting sharks. "Many shark populations are overfished, they're threatened," says Bakker. The first step for effective conservation programmes, she explains, is knowing which species are present and eDNA could help do just that.

FIRST GET THE DNA

The technique Bakker uses is essentially the same for all aquatic eDNA studies. First, she motors out to each sampling site at sea, scoops up a few litres of water and pours it through a fine filter to snag the DNA fragments from all the species that have recently swum by. Back in the lab, Bakker adds a primer that picks out of the mix all the fragments of shark DNA. Primers are short DNA or RNA strands that act like highly specific strips of Velcro and stick only to particular DNA sequences, in this

GETTY

HUNTING FOR ANCIENT BEASTS

For land-based scientists, a handful of soil can tell them which animals have crawled through it or flapped their wings overhead. A chunk of permafrost can even reveal whether, thousands of years ago, a woolly mammoth trudged past. A study of eDNA in Alaska suggests that mammoths were still alive until 10,500 years ago, almost 2,000 years later than previous estimates based on mammoth bones. If this new extinction date is accurate, it means humans and mammoths co-existed for several millennia.

Insights into past climates and ecosystems also come from eDNA. Ice cores taken from Greenland contain traces of eDNA from conifer trees and insects, showing that the land now lying under more than two kilometres of ice sheet, was once a flourishing forest.

This cutting-edge technology could also finally solve a centuries-old puzzle. An international group of scientists, calling themselves the Super Natural History team, is probing Loch Ness in Scotland. They plan to find out once and for all if a monster really does lurk in the dark depths. The eDNA sequences they decode should show if any unknown species are living down there, while also revealing a bigger picture of the biodiversity in this, the UK's biggest body of freshwater.

case only the codes specific to sharks. Next, she makes multiple copies of the shark eDNA fragments and feeds them into a high throughput sequencing machine. After 24 hours or so the machine produces huge data files with masses of DNA sequences, which she then compares with known DNA databases to work out which species the eDNA fragments came from.

Her studies have so far detected 21 shark species and shown that parts of the oceans protected from fishing have a greater shark diversity. In the Bahamas, where commercial shark fishing is banned, Bakker found eDNA from 11 species. In less well protected waters of Jamaica and Belize, she only found a couple of different sharks.

A major benefit of eDNA is that it's not invasive – you don't have to catch and handle sharks, which can stress them out. Also, the technique avoids any bias caused by behavioural quirks

In the Bahamas, where commercial shark fishing is banned, Bakker found eDNA from 11 species

of different species. "If you go fishing, you may catch five tiger sharks," says Bakker, "but perhaps you don't catch the bull sharks because they're just not attracted to your fishing line."

Another recent study in New Caledonia, led by Germain Boussarie from the University of Montpellier, showed just how well eDNA outperforms other surveys. Water samples collected during two weeks of fieldwork provided DNA that identified more shark species than were detected in two years' worth of underwater baited camera studies and thousands of scuba dives. The eDNA samples found sharks 90 per cent of the time, compared to only 50 per cent in camera studies, and 15 per cent in dive surveys.

But still some sharks are missing. Working in the Caribbean, Bakker and her colleagues regularly saw nurse sharks but failed to find any traces of their eDNA. The problem comes

GETTY, JUDITH BAKKER, BRIDGES

ABOVE: Judith Bakker collecting samples of seawater for the eDNA material it contains

BELOW: Remote control drones could be used to gather eDNA from the ocean depths

ALIEN SPECIES SURVEILLANCE

Environmental DNA makes an ideal early warning system for alien invasive species – creatures that find themselves in places they aren't expected or wanted. Given half a chance, many successful invaders will rapidly multiply and unleash economic and environmental havoc, like zebra mussels that block intake pipes of water treatment plants and Chinese mitten crabs that crumble riverbanks with their burrows. DNA fragments can show when a potentially invasive species is present in small numbers and hasn't yet become a pest. The sooner an invasion is discovered, the more likely control measures are to work.

From pondweed and clams, to fish and sponges, eDNA is used to monitor all sorts of invasive species. In the US, eDNA helps conservationists quickly find out if an invasive European pig has wallowed in a pond, or if it remains pig-free. With climate change, invasions are likely to become more problematic as temperatures rise and more species try to compensate by shifting their ranges. We're already seeing the spread of species into British waters, such as the carpet sea-squirt, a gloopy, fast-growing animal that smothers other sealife, including oysters and mussels in shellfish farms.

down to the primers. "They just don't like to attach to nurse shark DNA," says Bakker. Fixing this primer mismatching is one of the improvements she hopes to see in eDNA techniques in the coming years.

There's a goldilocks quality to DNA fragments in water: it doesn't vanish too quickly or linger too long to be useful. If the eDNA of a tiger shark is found, then one probably swam nearby in the last day or two. Any longer and DNA gets broken down by saltwater, UV light and bacteria until the fragments are too small to detect. Bakker is hopeful that advances in the technique will soon allow her not only to work out which sharks are there, but also how many of them. For now, eDNA can only give a rough guess at abundance. "We can say that most likely there's a lot more sharks in this area than that area," she says.

Off the coast of Greenland, a study has shown that eDNA could revolutionise the way fisheries are monitored. Researchers collected water samples and extracted eDNA from more than 30 fish families, including many that are important in commercial fisheries. The team found that the abundance of eDNA broadly matched the amount of fish they caught in conventional trawl surveys in the same area. The new technique could also help survey species that rarely show up in trawl nets. They found lots of eDNA from Greenland sharks, illusive giants that can live for 500 years. But the trawl surveys only caught one Greenland shark, suggesting that many others avoid the nets.

CALL IN THE DRONES

In the next few years, fisheries scientists could start to abandon trawl surveys and instead use eDNA to count fish. And to collect water samples, scientists might even throw away their buckets and start sending out fleets of drones and underwater robots to get water for them. Already there are ocean gliders that look like a cross between miniature submarines and aeroplanes, fitted out with scientific sensors and instruments. They can be programmed to navigate on their own for thousands of kilometres through the seas, gathering measurements as they go, like salinity and temperature. Equipped with water sampling devices, these robots could become the research tool of choice for eDNA studies, opening up remote stretches of the oceans that are otherwise difficult and expensive for scientists to get to, including down in the deep sea, many kilometres beneath the waves.

A SEA CHANGE

The deadline for global action on protecting the oceans is fast approaching. Will we hit the 2020 target? WORDS: **HELEN SCALES**

The United Nations set a target of safeguarding 10 per cent of the seas from humanity's impacts, such as fishing and drilling for oil and gas, by 2020. So far, the numbers look promising. The Protected Planet website (www.protectedplanet.net) lists more than 15,000 Marine Protected Areas (MPAs) covering roughly seven per cent of the oceans, up 10-fold since 2000.

Much of that growth comes down to several enormous MPAs including the Papahānaumokuākea Marine National Monument. Originally set up by George W Bush and expanded by Barack Obama, it includes remote coral reefs and islands stretching northwest from Hawaii and covers 1.5 million square kilometres, equal to the area of Spain and France put together. Other pledges include protecting a quarter of Brazilian waters and making 10 per cent of Belize's waters completely off limits to fishing.

DISPUTED FIGURES

It's too soon to start celebrating though: not everyone agrees that the 10 per cent target is within reach. "A lot of those areas have only been proposed," says Callum Roberts, professor of Marine Conservation at the University of York. An alternative assessment counting only legally implemented MPAs reveals a global area of four per cent. Or two per cent if it includes only sites that are highly protected from fishing.

Roberts is especially critical of countries, including the UK, which claim their waters are well-protected but where there's little active management. "We've got essentially a fake network of MPAs," he says.

The least-protected parts of the oceans are the high seas, distant reaches far from shore that make up roughly half the planet's surface and are vital for providing food and regulating the climate. Effectively a lawless realm that no countries can claim, the high seas have been largely neglected when it comes to conservation. But that could soon change.

By 2020, the United Nations also plans to create a new global treaty for the high seas making it easier to set up conservation zones that will protect migrating sea turtles, whales, tuna and sharks, not to mention the wonders of the deep sea. Negotiations are underway and the outcome will be vital if we're ever to reach the more ambitious target of 30 per cent ocean protection, as supported by many scientists including Roberts. "What happens in the high seas is fundamental to the processes that make this planet habitable for all of us."

"What happens in the high seas is fundamental to the processes that make this planet habitable for all of us"

A marine debris team collects fishing nets that have been abandoned in the Papahānaumokuākea Marine National Monument

NOAA

A FISH OUT OF WATER

How will Brexit affect UK fisheries?

WORDS: **HELEN SCALES**

In June 2016, an ungentlemanly battle broke out on the Thames between pop star Bob Geldof and UKIP leader Nigel Farage. They motored down the river followed by flotillas of angry supporters, slinging nasty insults at each other over the issue of Brexit and fishing. The UK fishing industry supports roughly 11,000 British jobs and makes up less than one per cent of the UK's GDP, but fishing has been one of the hot topics of Brexit.

At the heart of the wrangling is the EU's Common Fisheries Policy (CFP), which for decades has set rules on what British boats are allowed to catch and bring back to shore, and where they can fish within European waters, including those belonging to the UK. The CFP allows other European countries to fish in UK waters – unpopular with many British fishers.

The UK government has pledged to withdraw from the CFP although only two years after Brexit. Then British fisheries scientists will be in charge of conducting yearly surveys of the state of fish stocks in British waters and offering advice on how much of each species can be caught sustainably, and by whom. As well as setting their own catch quotas, the government has said it will find a way of stopping so-called discards, the practice of throwing dead fish back into the sea because there's no quota for them.

A big unknown is whether EU vessels will be banned from British waters. It was one of many promises made by the Leave campaign, but it could turn out to be a bit of a red herring. One problem is the fact that at least half of all British-caught seafood is exported to Europe. To keep selling British catches to the EU and avoid costly trade tariffs, the UK government may have to concede access to their waters.

A big unknown is whether EU vessels will be banned from British waters

Most of the seafood actually eaten in Britain is currently imported, including the much-loved chip shop staples, cod and haddock. These cold-water species are moving northwards, as climate change warms the seas, so stocks in British waters could dwindle. If Britain closes its fishing grounds to European fleets, perhaps we'll start seeing more local species, like crabs and cuttlefish, on British menus.

GETTY

TALKING POINT

BREXIT BATTLE

How the UK's departure will affect scientific research

WORDS: **TANIA RABESANDRATANA,** *Contributing Correspondent for the journal* ***Science***

The United Kingdom is scheduled to leave the European Union at 11pm on Friday 29 March. Like most areas of British society, science and tech will be affected by the divorce.

Chief among the concerns of UK researchers is, well, money. Scientists in Britain have a strong record of earning EU research funds, second only to Germany and above France. UK scientists want to be able to keep tapping into Horizon 2020, the EU's big seven-year science funding pot, and its successor Horizon Europe, that will start in 2021. This will require paying into the programme through an association agreement, like countries such as Norway.

If there is no deal before Brexit, the UK will become a third country to the EU come March. UK researchers would lose access to three major Horizon 2020 funding lines that make up about 45 per cent of the €4.79 billion (£4.19 billion) received by UK organisations since 2014.

UK scientists want to keep tapping into the EU's funding pot

Besides hard cash, Britain is set to lose less tangible science currency – influence and reputation. "All Brexit deals look like different shades of bad" for UK research, says Mike Galsworthy, director of the pro-EU campaign group Scientists for EU. "If we have a deal, our policy influence steps down but we are still loosely in the ecosystem." A no-deal Brexit would be a "sudden shock" with "lots of broken contracts all over the place to catch up on," he says. Science would become just one, lower-priority item on a long list of issues for the government to negotiate.

Prof Alison Smith, a plant scientist at the University of Cambridge, who has been involved in several EU-funded projects, says her field of algae biotech needs easy cooperation across borders and disciplines to develop. "In my field you have to be able to know about engineering, regulation, how to scale up. It's not possible to do with just one lab," she says. Negotiations have already slowed down cooperation, made it harder to recruit the best researchers and "limit the opportunities for the UK to have leadership" in a still-growing area, she adds.

While a survey in the journal *Nature* showed that most UK researchers opposed Brexit, some see a silver lining – freeing the country from constrictive EU regulations.

"Leaving the EU should, in theory, free us from bureaucracy," says Prof Angus Dalgleish, an oncologist at the University of London. "Several areas of research, such as GMO and stem cell research, could be expected to take a significant lead when free of the specific EU regulations that inhibit these areas at present."

In any case, one lasting Brexit side-effect is that science has gained importance in political debates. Since the vote, all three major parties have recognised its key role in Britain's economy and pledged to boost research budgets.

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